Politecnico di Milano
School of Architecture, Urban Planning and Construction Engineering Master's Degree in Building and Architecture Engineering

Assessment of BIM in construction management: the impact of WBS, QTO, cost estimation and time analysis on decision making policy for optimization of energy efficiency

Rokhsareh Assarehpour
Student ID: 927017

Thesis Advisor: Prof. Alberto Pavan
Thesis Co-advisor: ARC Elisa Sattanino

Academic Year 2021/2022

Table of Contents

I. List of Tables

II. List of Figures

III. Abstract

In Europe, the argument over the relevance of global building sustainability (covering energy, environmental, social, economic, and political issues) is becoming increasingly relevant. In this context, the restoration of existing buildings, particularly those with large volumes and low energy performance, receives considerable attention, however the age of building is another involved factor that must be considered.

On the other hand, over the previous few decades, the term of "Building Information Modeling," or BIM, has evolved from a term with a few early adopters to the heart of AEC technology, which encompasses all aspects of building design, construction, and operation. Almost every major design, engineering, and construction firm in the world has switched to BIM from their prior, drawing-based CAD technology. In a more precise sense, BIM in the construction management industry gives not just clients but also project managers the ability to model and estimate crucial project characteristics such as time and cost before they are realized.

The major purpose of this project is to represent a decision-making route based on two most important parameter in project management which are cost and time, for reconstructing or renovating an existing building using BIM software in order to achieve a satisfactory energy grade in the building.

The cost and time parameters will be used to evaluate this project, which are also influenced by Take Off Quantity (TOQ) and Work Breakdown Structure (WBS). This project makes use of a variety of BIM applications including, 3d modeling for modeling, Quantity take off software for TOQ, Excel and management platform for cost and time estimation and Energy simulation software.

Key word: BIM, Reconstruction, Renovation, Cost estimation, Time estimation, energy efficiency

1 Introduction

1.1 Building Information Modeling (BIM)

1.1.1 Definition

One of the most promising advances in the architectural, engineering, and construction (AEC) industry is building information modeling (BIM). One or more accurate virtual models of a building are created digitally using BIM technology, where they will assist designers throughout the design process, enabling for better analysis and control than manual methods. When finished, these computer-generated models contain the precise geometry and data needed to assist the building's construction, manufacturing, and procurement activities. BIM also accommodates many of the tasks required to model a building's lifecycle, laying the groundwork for new design and construction capabilities as well as changes in project team responsibilities and relationships. When properly implemented, BIM allows for a more integrated design and construction process, resulting in higher-quality buildings at cheaper costs and shorter project timelines.(John Wiley & Sons, 2011)

In national building The BIM was defined by the Information Model Standard Project Committee as follows:

“A BIM is a digital representation which serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward.”(Bryde et al., 2013)

Building Information Modeling (BIM) is becoming a comprehensive collaborative process in the construction industry. BIM has grown in popularity steadily over the previous decade. This is primarily due to its building project management abilities. BIM enables all project participants and system divisions to communicate in a same language, producing a cohesive team. The approach of BIM lends itself nicely to integrated project delivery systems.(Rokooei, 2015). BIM is a modeling technique for producing, communicating, and evaluating architectural models, as well as a collection of related activities.

Building models have the following characteristics:

Building elements with digital representations (objects) that can be recognized by software applications and have parametric rules that allow them to be altered intelligently.

Takeoff, description, and energy analysis are just a few of the components that make up data that explains how they behave, which is useful for studies and job operations. Changes to component data are reflected utilizing coherent and non-redundant data in all viewpoints of the component and the assembly of which it is a part. Using synchronized data, all perspectives of a model are recorded in a coordinated manner. (John Wiley & Sons, 2011)

1.1.2 Benefits

The management of construction projects is becoming increasingly complex and difficult. One source of complexity is the reciprocal links among various parties, including finance bodies, authorities, architects, engineers, lawyers, contractors, suppliers, and crafts. Information and communication technology [ICT] has been evolving at a breakneck speed in response to the increasing complexity of projects. Building Information Modelling [BIM] has proliferated in corporate and academic circles as the new Computer Aided Design (CAD) paradigm throughout the previous decade, signaling a significant shift in ICT for the building industry. Building Information Modeling (BIM) is the most widely used abbreviation for a new approach to building design, construction, and maintenance. It is defined as "a combination of interconnected rules, processes, and technologies that generate a system for managing important building design and project data in digital format throughout the life-cycle of the building". BIM has been used on high-profile large-scale projects such as the recently completed London 2012 Olympic 6,000-seat Velodrome cycling track and the 48-story Leadenhall Building "The Cheesegrater," which, when completed in 2014, will be one of the city's highest structures at 225 meters. BIM is employed on individual components of smaller-scale projects in addition to large-scale ones.

For example, BIM was used to design and install the modular stairs at the modern bus station in Slough, UK, which opened in June 2011. The UK Government has stated that all contracts won from 2014 onwards will require procurement members to work collaboratively by the use of BIM technology, which can develop and enhance many business practices, anticipating benefits from the use of BIM in terms of reduced transaction costs and less opportunity for errors. Despite the fact that the AEC/FM (facility management) business is still in the early stages of BIM adoption, significant gains have already been made (compared to traditional 2D CAD or paper-based practices). Though it's unlikely that all of the benefits listed below are presently in use, we've included them to demonstrate the breadth of changes that can be predicted as BIM technology progresses.(Bryde et al., 2013)

BIM technology and related processes are at the core of how the building design and construction method can respond to the increasing pressures of greater complexity, shorter lead times, and improved conservation while lowering the cost of the project and its subsequent use, as shown in Figure 1.

These demands are beyond traditional practice's ability to respond. The sections that follow provide a quick overview of how this improved performance can be accomplished.(John Wiley & Sons, 2011)

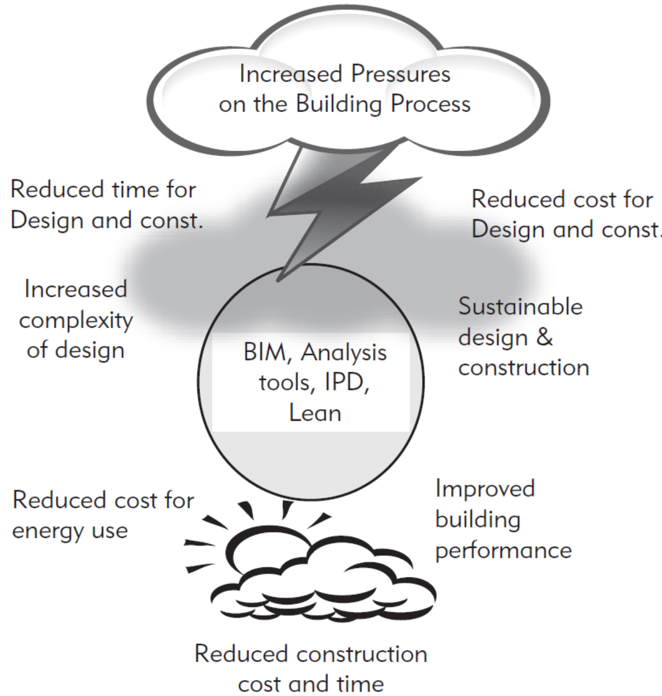


Figure 1: BIM assistance in reduction of cost and time in construction (John Wiley & Sons, 2011)

BIM can create a common language between all parties and system divisions in a project and make them an integrated. The service supply process is currently fragmented, and it relies on paper-based communication. Failures in paper documents can result in unexpected field costs, delays, and disputes between project team members. Friction, financial costs, and delays are all caused by these issues.

Alternative organizational structures, such as the design-build process, have been used to overcome such issues, as has the use of real-time technology, such as project Web sites for exchanging plans and data, and the adoption of 3D CAD tools. While these technologies have enhanced the speed with which information is exchanged, they have done little to diminish the severity and frequency of conflicts generated by paper records or their electronic substitutes. (John Wiley & Sons, 2011)

One of the most typical issues with 2D-based communication throughout the design process is the significant time and cost involved in generating critical evaluation information about a proposed design, such as cost estimates, energy-use analyses, structural details, and so on.

These evaluations are usually carried out last, when it is too late to make significant adjustments. Because these incremental improvements do not occur during the design phase, value engineering must be used to overcome inconsistencies, which frequently results in design compromises. (John Wiley & Sons, 2011)

Irrespective of the contractual approach, certain numbers, such as the number of employees participating and the volume of data collected, are common to practically all large-scale projects ($10 million or more). Maged Abdelsayed of Tardif, Murray & Associates, a construction firm in Quebec, Canada (Hendrickson 2003), collated the following information:

- 420 participants (businesses) (all suppliers and sub-subcontractors included)
- 850 people (individuals) took part in the study.
- The total number of different sorts of documents produced is 50.
- The total number of pages in the docs is 56,000.
- 25 bankers boxes will be used to store project documents.
- There are six 4-drawer filing cabinets in all.
- To make this amount of paper, 6 20-inch-diameter, 20-year-old, 50-foot-tall trees were used.
- 3,000 megabytes of electronic data are required to hold this volume of paper (scanned).
- 6 compact discs (CDs) is the same number of compact discs (CDs).

Regardless of the contractual approach adopted, managing an effort involving such a vast number of people and documents is difficult. The typical members of a project team and their multiple corporate boundaries are depicted in Figure 2.

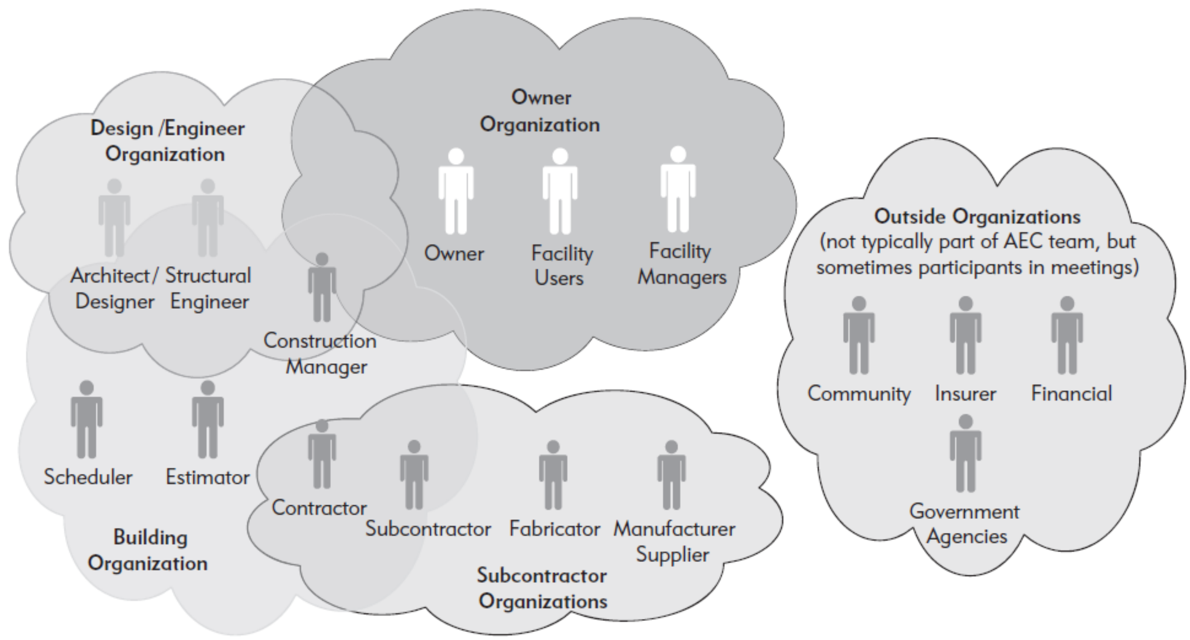


Figure 2: An AEC project team and conventional organizational units are depicted in this conceptual diagram. (John Wiley & Sons, 2011)

In 2002, about 90% of public buildings and about 40% of private structures were constructed following the Design-Bid-Build (DBB) method (DBIA 2007). More competitive bidding to obtain the lowest feasible price for an owner; and less political pressure to select a certain contractor are the two key advantages of this technique. The usual DBB procurement process, as compared to the normal Construction Management at Risk (CM at Risk) and Design-Build (DB) procedures, is schematically depicted. The client (owner) hires an architect, who creates a list of building needs (a program) and determines the project's design goals. Schematic design, design development, and contract papers are all processes that the architect goes through (Figure 3).(John Wiley & Sons, 2011)

The final documents must comply with local building and zoning standards as well as the program's requirements.

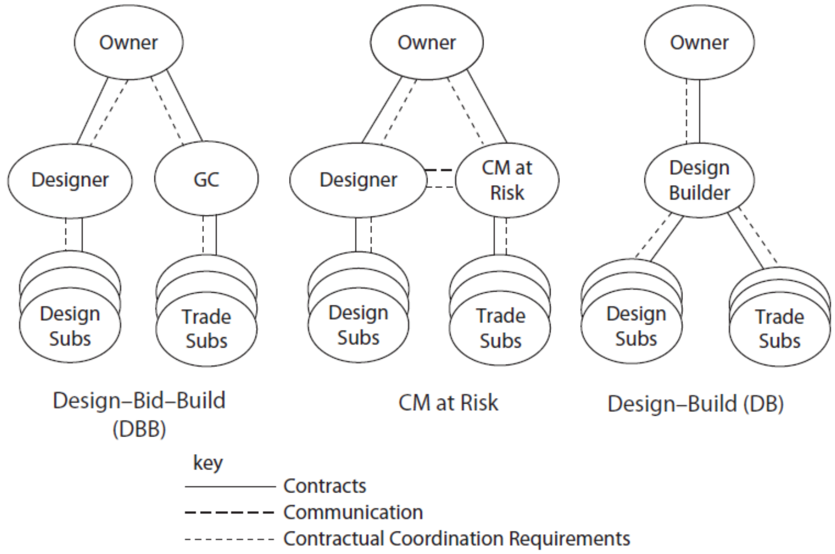


Figure 3: Schematic diagram of Design-Bid-Build, CM at Risk, and Design-Build processes.(John Wiley & Sons, 2011)

To aid in developing structural, HVAC, piping, and plumbing components, the architect either recruits' personnel or contracts specialists. These designs are captured on drawings (plans, elevations, and 3D visualizations), which must be synchronized in order to reflect all changes as they occur. To facilitate building bids, the final set of drawings and specifications must have enough detail. Due to the risk of lawsuit, an architect may choose to provide fewer information in the drawings or to include text stating that the drawings cannot be relied on for dimensional correctness.(John Wiley & Sons, 2011)

As errors and omissions are found and responsibility and additional costs are shifted, these tactics frequently lead to disagreements with the contractor.(John Wiley & Sons, 2011) The second stage entails soliciting bids from construction companies. The owner and architect may have a say in which contractors are allowed to bid. A set of drawings and specifications must be submitted to each contractor, which will be utilized to produce an independent quantity survey.

A along with bids by subcontractors, are then utilized to calculate a cost estimate. Subcontractors chosen by the contractor must repeat the same process for the portion of the project in which they are working. Contractor (general and subcontractors) usually spend about 1% of their expected expenses generating bids due to the effort involved. The cost per successful bid ranges from 6 to 10% of the total project cost if a contractor wins one out of every six to ten tasks that they bid on. This cost is then added to the overhead costs of the general owner and contractor.(John Wiley & Sons, 2011)

The chosen bidder is usually the one who submits the lowest responsible bid, which includes both the general contractor's and subcontractor' work. Before work can begin, the contractor must frequently redesign some of the designs to reflect the construction process and job phasing. General arrangement drawings are what they're called.

Subcontractors and manufacturers must also create their own shop drawings to reflect exact features of precast concrete modules, steel connections, wall details, pipe runs, and other elements. Shop drawings, which are the most comprehensive representations and are utilized for actual manufacture, require accurate and full drawings. If these drawings are erroneous or inadequate, or if they are based on drawings that already contain flaws, inconsistency, or omissions, the field may face costly and time-consuming conflicts. The financial repercussions of these conflicts can be significant.(John Wiley & Sons, 2011)

Fabricating materials offsite is problematic due to design inconsistency, inaccuracy, and uncertainty. As a result, the majority of fabrication and construction must occur on-site and only after precise conditions have been established. On-site construction work is more expensive, takes longer, and is more likely to make errors than work done in a factory setting, where expenses are cheaper and quality control is stronger. (John Wiley & Sons, 2011)

As a result of previously unseen faults and omissions, unexpected site circumstances, changes in material availability, queries about the design, new client requirements, and new technology, significant changes to the design are frequently made during the building process. The project team must resolve these issues.

Each change necessitates a procedure to identify the root cause, assign responsibilities, assess the time and cost implications, and determine how the problem will be remedied. This approach requires a Request for Information (RFI), which must be replied by the architect or other relevant party, whether initiated in writing or through the use of a Web-based platform. Following that, a Change Order (CO) is issued, and all affected parties are notified of the change, which is transmitted together with any necessary revisions to the drawings.

Frequently, these adjustments and settlements result in court conflicts, additional expenditures, and delays. Although web site tools for managing these transactions assist the project team in staying on top of each change, they are of minor use because they do not address the heart of the problem.

When a contractor bids less than the expected cost in order to win the job, problems develop. Contractors frequently take advantage of the change process to recuperate losses from the initial bid. As a result, there are more disagreements between the owner and the project team.(John Wiley & Sons, 2011)

Furthermore, the DBB procedure mandates that all materials be held until the owner approves the offer, which implies that products with significant lead times may cause the project to be delayed. The DBB strategy takes longer than the DB approach for this and other reasons. The final process is commissioning the building, which occurs after it has been completed. This entails ensuring that the building's systems (heating, cooling, electrical, plumbing, fire sprinklers, and so on) are operational. Final drawings are subsequently generated to reflect any as-built alterations, and these are supplied to the owner together with all manuals for installed equipment, depending on contract requirements. The DBB process is finished at this stage.

Because all of the information provided to the owner is in 2D (on paper or equivalent electronic files), the owner must exert substantial effort to ensure that the facilities management team entrusted with maintaining and operating the building receives all pertinent information. The procedure is time-consuming, error-prone, and costly, and it continues to be a significant impediment.(John Wiley & Sons, 2011)

1.2 Construction management

Construction planning and preparation entails arranging activities in space and time while taking into account procurement, resources, geographic limits, and other factors. Bar charts were traditionally used to organize projects, but they couldn't show how but also why different operations were connected in a particular order, nor could they compute the longest (important) path to completion. Today, schedulers develop, maintain, and communicate the schedule utilizing a range of reports and displays using Critical Path Method (CPM) scheduling software such as Microsoft Project, Primavera SureTrak, or P3.

These systems display how activities are connected and allow for the computation of critical path(s) and floating values, which help with project scheduling. Schedulers can use specialized software programs, like as Vico Control 2009, that are more suited to construction process, to execute location-based scheduling, which helps schedule workers doing repeated work in several places.

Some of the packages also include sophisticated planning techniques for resource-based analysis, such as resource-leveling and scheduling with uncertainty in mind, such as Monte Carlo simulation. Other software tools exist for creating precise timetables for short time spans of one or two weeks that take into account individual substitutes, material availability, and so on.

Traditional methods, on the other hand, fail to capture the spatial aspects of these activities and do not connect directly to the design or building models. Scheduling is a labor-intensive operation that frequently falls out of sync with the design, making it more difficult for project stakeholders to understand the schedule and its implications for site logistics.

In Figure 4 that is a standard Gantt chart, demonstrating how difficult it is to assess the construction implications of this timetable display. (John Wiley & Sons, 2011)

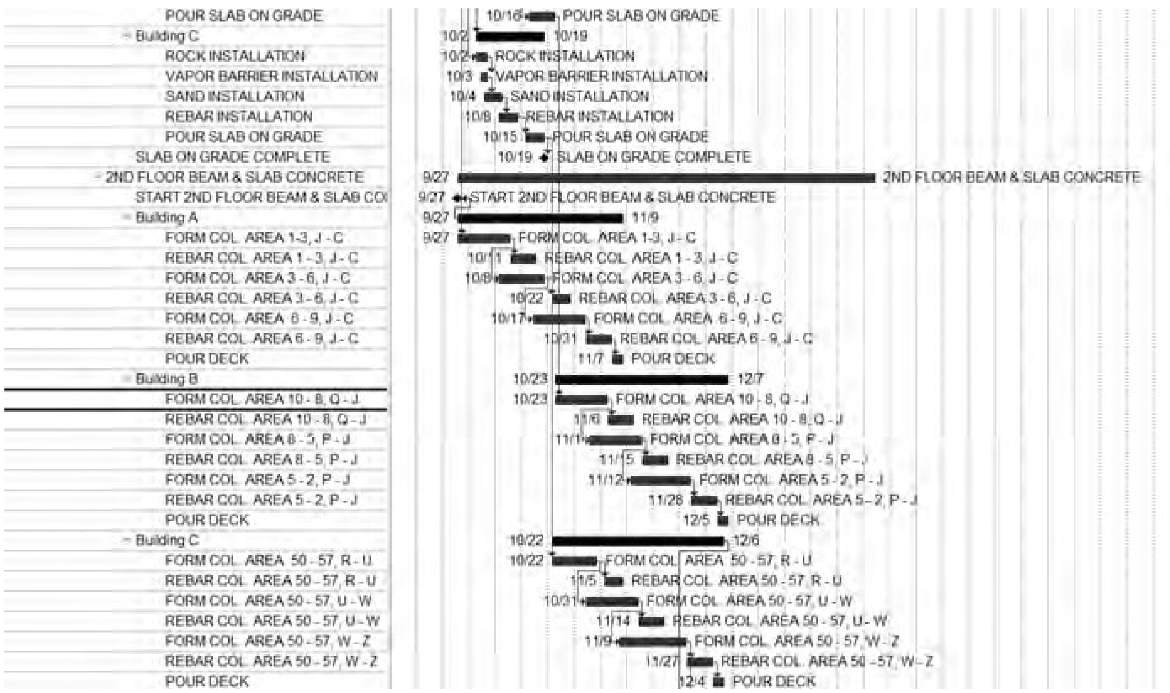


Figure 4: Sample Gantt chart of a construction schedule for a project involving three buildings and multiple floors and areas.

Many project team members find it hard to assess the feasibility or quality of a schedule based on a Gantt chart since there are no visual associations with the referenced areas, such as "Area 10" to a drawing or diagram. This necessitates manually allying every activity with areas or elements in the project. Only those who are intimately familiar with the project and how it will be built can assess whether this timeframe is realistic. To remedy these flaws, two types of technology have emerged. The first is 4D CAD, which is defined as 3D models with time linkages. The construction timetable is linked to the 3D model, providing for visual representation of the building's sequential construction. Schedulers can use 4D CAD tools to visualize and explain tasks in the context of place and time. Movies or virtual simulations of the schedule are 4D animations.(John Wiley & Sons, 2011)

To optimize activity sequencing, the second strategy is to use analysis tools that include BIM components and building method information. These technologies take into account information such as location, resource use, and productivity. The following sections go over these two ways. As part of Lean building methods, a third option is gaining traction. The primary ideas of "pull driven" scheduling are the construction of a feasible backlog of tasks and the assignment of tasks from the backlog to teams for execution only if and when they are ready for execution.(John Wiley & Sons, 2011)

In practice, this typically means that work teams only take on assignments if all conditions have been met, thereby deferring jobs until the "last responsible moment." This method to detail level scheduling (the next one to three weeks) is actually production control, and the technology is known as the Last Planner System TM (Ballard 2000). It can be aided by BIM in a variety of ways, including the visualization of the construction process. There are some ERP systems/platform that allow designers and AEC companies to manage costs, time, resources and activities in order to have all the process under control. Among this ERP systems, there are:

- Oracle ERP
- TeamSystem Construction: (https://www.teamsystem.com/construction/)
- INTELSYS.build (http://intelsys.build/solution/)
- MTWO Complete Construction Cloud: (https://www.mtwocloud.com/5d-bim)

1.3 BIM in construction management

BIM has a unique background in construction management.It's critical to comprehend this one-of-a-kind evolution in order to fully comprehend its significance and trajectory.

We recognize the value of BIM as a practical tool and aspirational concept. In the Architectural, Engineering, and Construction (AEC) industries, BIM has been credited with various accomplishments. We emphasize the importance of laying the groundwork for computer-assisted collaboration settings and integrated procedures.(Wierzbicki & De Silva, 2011)

BIM as a concept represents AEC activity and promotes debate about the future of the architecture profession.It brings academics and professionals together and serves as a focal point for their differing perspectives. This concept is used to theorize BIM's potential and constraints in the future.Despite the fact that BIM is a symbol of collaboration, the competitive nature of corporate branding and market supremacy has resulted in a plethora of BIM services that are incompatible with one another. (John Wiley & Sons, 2011)

The numerical precision paradigm of CAD is the foundation of BIM. As a result, it has a hard time interacting with ideas in the early phases. We believe that continuous developments in computer technologies are driving the trend toward complex, highly integrated tools and workflows. In this scenario, BIM has the power to expand along and across workflows and processes.(Wierzbicki & De Silva, 2011)

We examine BIM's internal and external problems, as well as its potential future directions. We believe that BIM's unique contribution to the AEC industry is in offering a baseline and a course. BIM has positioned the AEC sector as a medium for regional and global collaboration in the design and development of built environments since its inception.BIM, as we know it, is largely based on Parametric Tools Corporation's object-based parametric modeling technologies, which were developed in the 1980s. (John Wiley & Sons, 2011)

1.3.1 History

In the early 1990s, BIM for the construction industry became commercially available as a tool, thanks to computers' ability to manage the size and processing requirements of 3D CAD models. Because of its capacity to combine several BIM filetypes, Autodesk's acquisition of Quantity take off softwares in 2007 acted as a spur for BIM adoption among contractors.

Between 2007 and 2010, as BIM became more widespread, the number of add-on applications, services, and hardware linked with this exciting new tool increased dramatically. The two new dynamics we mentioned before were formed by the increase in the number of BIM-related plugins, add-ons, and applications. The first dynamic was the early stages of the technology "renaissance," which shifted the focus to the construction industry and its technological capabilities (Figure 5).

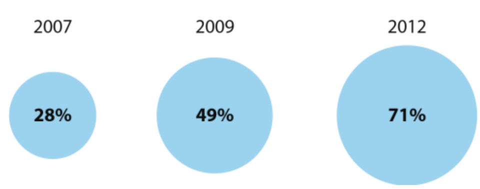


Figure 5: Leve of BIM development in North America (MCGRAW-Hill Construction America)

The challenge provided to construction businesses in selecting the correct BIM technologies that worked together to create value was the second dynamic created. This period in BIM history was widely regarded as the start of BIM, and it quickly prompted a call to action among these tools on the topic of interoperability and free data exchange between systems, which is still a topic of debate today. (Rogério dos Santos Alves; Alex Soares de Souza, 2014)

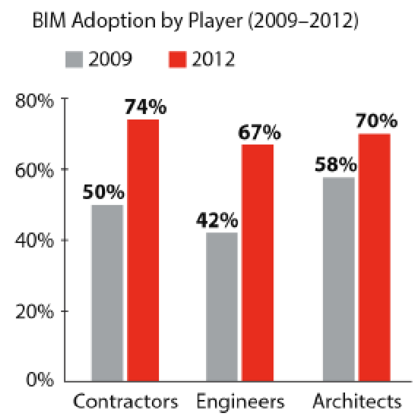


Figure 6: BIM adoption by player (2009-2012), (Rogério dos Santos Alves; Alex Soares de Souza, 2014)

To differentiate themselves from their competitors, some early investors began adopting BIM technologies into their firms. Many companies tried to sell their own brand of BIM as something unique that only they knew about and that no one else had. It became increasingly important to stand out from the growing BIM crowd, whether through key employees, project experience, or custom-developed technologies.

Many early adopters questioned the context and utility of BIM tools and process flows, and it appeared that the tournament was entirely based on who possessed the next forthcoming tool, as mentioned previously in this chapter. In addition to making them more competitive, this caused many new consumers to doubt the context and usefulness of BIM tools and workflows.

Finally, this served as a catalyst for additional in-depth reflection and inquiry. Another reason driving the rise in innovators and early adopters is the demand for BIM from forward-thinking construction organizations. Among them are the Universal Service Administration (GSA), the United States Army Corps of Engineers (USACEI), Disney, Google, Coca-Cola, and other major construction clients. For construction companies to remain relevant to these customers, they needed a compelling technical approach based on proven deliverables and reliable outcomes.(Rogério dos Santos Alves; Alex Soares de Souza, 2014)

Many experts predicted that BIM as a tool and technique would take decades to achieve popularity. Although early efforts were slow and followed the trend line of a traditional technology integration cycle Figure 7, BIM has since taken the AEC industry by storm, with BIM adoption increasing from 28% in 2007 to 74% in 2012 (source: RIM SmartMarket Report, "Business Value of BIM in North America") and going fast from early to middle to late stages of implementation. After the dust settled from the initial excitement and optimism, the early majority displaced the early adopters, who explored these new technologies at a far deeper level than surface promises. Finally, these experts began to assess which tools were clearly valuable and delivered on their promises, as well as which ones were not. To collect this data, many communities and institutions were founded.(Rogério dos Santos Alves; Alex Soares de Souza, 2014)

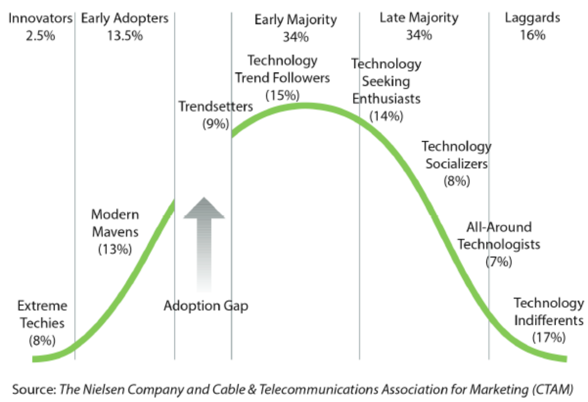


Figure 7: Traditional technology adoption cycle (Rogério dos Santos Alves; Alex Soares de Souza, 2014)

The factors that influenced the use of BIM altered from 2007 to 2012 are shown in Figure 8. Owners requiring BIM on their projects was the second-largest driver in growing BIM use in 2007.

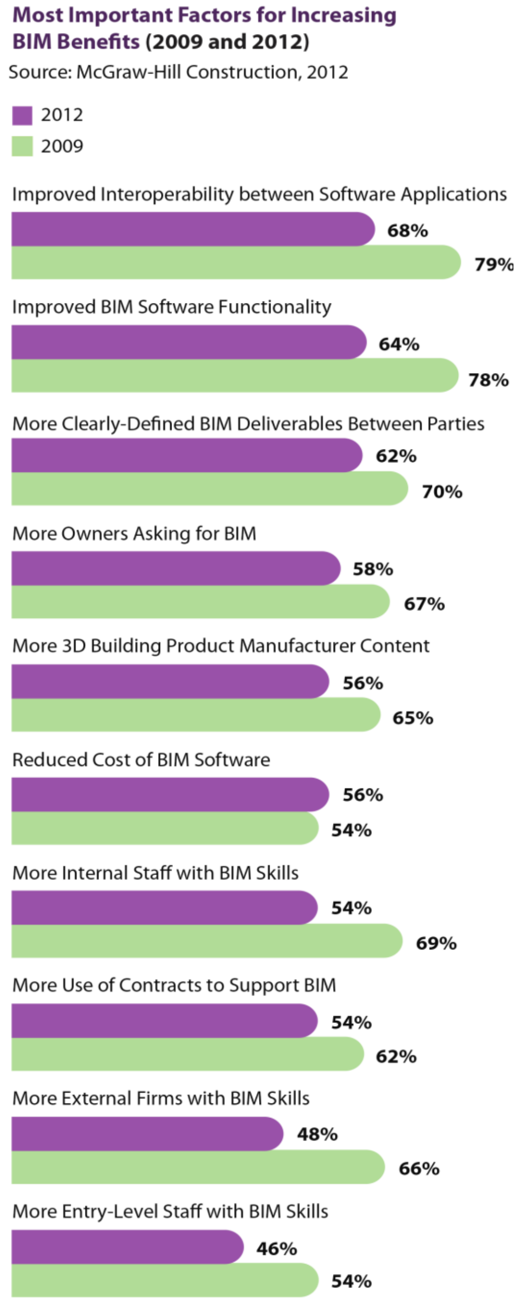


Figure 8: factors that influenced the use of BIM altered from 2007 to 2012, Mc Graw-Hill 2007

The construction industry appears to be on the approach of adopting BIM, despite the fact that owner needs remain a prominent influence. As more professionals from around the world dig into the capabilities and potential of BIM in construction, evidence of more in-depth inquiry and analytical thinking associated with the cautious early and late majority adoption cycle group continues to emerge. In the traditional technology acceptance cycle, inventors, early adopters, and trendsetters pass the torch to the early and late majority, which is roughly where BIM is in its technology adoption life cycle right now. (Rogério dos Santos Alves; Alex Soares de Souza, 2014)

The early to mid majority of users are more analytical than "techies" and have had a significant impact on BIM adoption, having more say than their forebears in terms of processes, data quality, and organization. Large amounts of data that house or link to parametric (model) components, as well as tool interoperability, remain a top priority. The industry is still defining the value of BIM information as a whole. This gives up a wide range of options for future developments that will go through several technological cycles.

Many industry groups host lectures and debates that go beyond simply introducing BIM as a theory to a more in-depth look at planning, organizational structures, and process change dialogue. BIM and construction technologies are at an all-time high right now. New technologies and approaches that are similarly focused on value, aligned with processes, and consolidate functions are currently on the market. (Rogério dos Santos Alves; Alex Soares de Souza, 2014)

So we can understand how substantial the implications are for estimating, scheduling, trade coordination, and installation when we consider the potential uses for a virtual model that can hold information about each individual door, roof top unit, slab, and window. Model creation and use efficiency will continue to increase in the design and building industry.

As a result, teams are investigating ways to harness the data and information created by models to eliminate waste in redundant data entry and points of input, as well as to uncover trends, patterns, and concerns that we couldn't see before BIM. (Rogério dos Santos Alves; Alex Soares de Souza, 2014)

1.3.2 BIM benefit for project manager

Potential benefit of using BIM for project managers Potential benefit for PMs are;

1.Organize the project schedule and budget work well with the Design Team because of An integrated 5D BIM model immediately updates both the schedule and budget when any design change occurs By using the integrated 5D BIM model to visualize and explore the impact of changes, s/he can keep project scope in check and become a trustworthy liaison between the designers and Owner.

2. Hiring and controlling the Subcontractors Requests For Information (RFIs) and Change Orders because of Having a handle on clash detection and coordination plays a key role in keeping Sub-contractors' work predictable Utilizing Coordination Resolution in preconstruction, these numbers can be brought to near zero.

3. Optimize the Owner's experience and satisfaction because of Owner received a big injection of confidence in the GC when the PM showed him/her how design decisions impacted cost and schedule

4. Project closeout since PM to present a 6D BIM a facilities resource with information on warranties, specifications, maintenance schedules, and other valuable information

5. Profit margin in order to understanding the project in SD, the PM has more tools at his disposal to keep tight reins, and more reports to monitor progress

6.Progressive Owners are mandating BIM on their projects: Becoming the BIM expert, in both preconstruction and out in the field, makes the PM invaluable and a key player.

7.PM Firm Growth since Project's success with SD BIM means the opportunity to grow the firm's reputation and helps the corporate team win new business.

1.3.3 BIM software progress

Collaboration is critical to BIM, according to researchers. This partnership grows in two directions. First and foremost, BIM is a CAD interoperability tool that connects all AEC disciplines' design models and files. Second, BIM is an Information Management platform that facilitates simultaneous collaboration among all participating teams as well as within them. Although CAD interoperability has been around for three decades and is supported by standardized data exchange formats like as SAT, STEP, and IGES, it is primarily a one-way, quasi interpretation. BIM is more difficult to implement because it relies on two-way, interactive, and on-the-fly parametric data coordination.

However, rather than being a technological breakthrough, such extended data sharing functionality is an incremental improvement.

Collaborative team environments, on the other hand, are a relatively new technology, having been pioneered by projects such as TeamMate, Teamwork, O.P.E.N., truEVault, and Quantity take off softwares in the second half of the 1990s, coinciding with the development of Enterprise Resource Planning (ERP) tools, which integrated information flow across entire organizations. In addition, all of these new collaboration tools required the use of cutting-edge networking technology such as the Internet and Gigabit Ethernet. (Wierzbicki & De Silva, 2011)

Because all major developers have quickly incorporated their collaboration capabilities with their various AEC packages, the introduction of collaborative technology represents the tentative inception of BIM. 3D modeling was already universally parametric at the time. The various strategies adopted by the key market participants are noteworthy. Bentley and Nemetschek's products are built on their main CAD platforms, which are constantly updated.

Before adapting and incorporating new CAD technologies, Autodesk attempts a few different ways. By acquiring alternative AEC/BIM platforms, Bentley and Nemetschek broaden their market offerings. The BIM's lauded integration, interoperability, and cooperation are a careful balance of several distinct technology, as evidenced by the wide range of techniques and components .(Neff et al., 2010) In every situation, 3d modeling serves as the foundation for the final output.

Even this fundamental component, however, is a mixed bag of surface and solid modeling techniques. Despite the fact that this phrase is usually associated with BIM, it could be the consequence of an idealized projection rather than genuine characteristics. A process is defined by academics as a set of actions aimed at translating inputs into a desired result. (Wierzbicki & De Silva, 2011)

'Decision,' 'purpose,' 'learning,' 'expertise,' and 'quality' are additional and related aspects of a process. Furthermore, the term process encompasses a broad range of applications, from industrial automation to complete commercial enterprises. In every situation, the process is temporal and involves a series of steps. A tool can be thought of as a process's low-level component. (Wierzbicki & De Silva, 2011)

Some logical steps of a process may be implied by a tool. However, by itself, it reveals nothing about the organization's objective, expertise, or choice. The tool can only be useful in defining such attributes if it is used in the context of a process. BIM, in its current state, has more tool-like characteristics.

Nonetheless, this begs the question of whether BIM can be turned into a process, what would be required to do so, and whether there is a compelling incentive to seek BIM's extended capabilities. Business Process Modeling (BPM), which began at the same time as BIM, became the focus of intense research and development on both theoretical and practical levels. (Wierzbicki & De Silva, 2011)

The rise of BPM software companies such as SIMUL8, Metastorm, and CreateASoft paralleled the rise of Information Management (IM) technology. When BIM and BPM are combined, a system capable of governing all actions in a company is created. However, it's critical to understand the conceptual distinctions between BIM and BPM. In order to handle a wide range of architectural projects, BIM must be a reasonably open-ended and transparent production tool. BPM becomes a distinctive and largely permanent manifestation of an organization's policies on efficiency, quality, purpose, and ethics once it is adopted.

As a result, BPM can take on a supervisory function, monitoring project delivery efficiency, managing project management elements such as human resource assignments, and tracking the quality of communication among team members, groups, and external stakeholders.(Wierzbicki & De Silva, 2011)

1.3.3.1 BIM tools history

The graph in the following depicts the evolution of software technology in relation to market activities. Different strategies were used by the major players in the sector. Some companies depended on their core CAD platforms and created BIM solutions on top of them. Others created totally new modeling engines from the ground up (Autodesk). In every case, 3d parametric modeling was founded on a sophisticated mix of CAD and AEC technology. (Wierzbicki & De Silva, 2011)

It becomes the complete BIM solution once it is connected with a preferred Information Management system. In the late 1990s, instant messaging (IM) technology took off. CAD and AEC became universally parametric around the same time. BIM was created by combining AEC and IM. This flurry of software development activity paralleled a protracted era of exponential economic expansion that lasted until 2001. Following it, technological advancements tended to be limited to small steps forward. (Wierzbicki & De Silva, 2011)

The market's activity was primarily centered on acquisitions. One of these acquisitions put an end to Graphisoft's independence as a prominent BIM software pioneer. (Wierzbicki & De Silva, 2011)

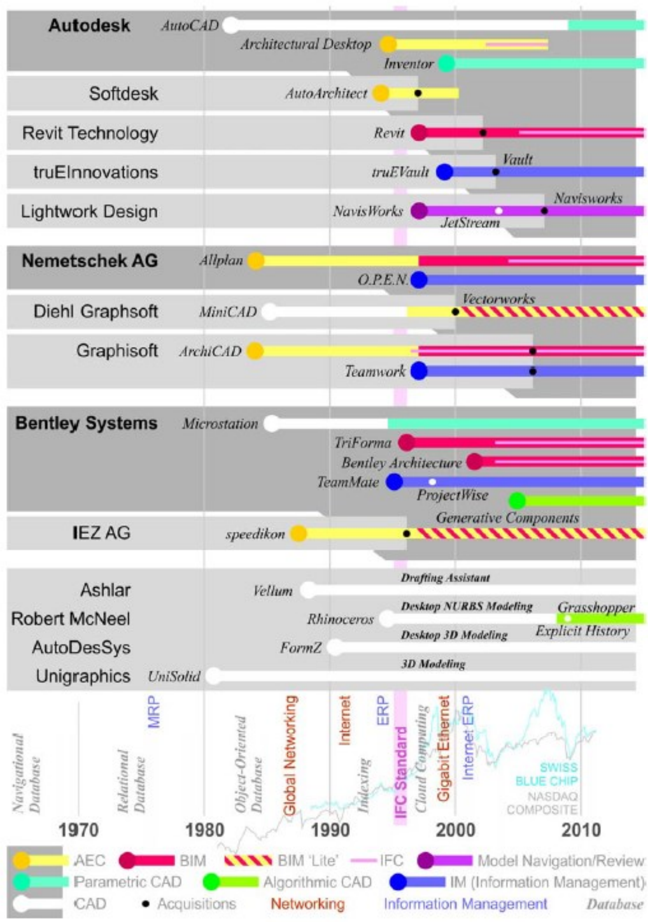


Figure 9: Technology and chronology (Wierzbicki & De Silva, 2011)

1.4 Work breakdown structure

A work breakdown structure allows for the summarization of subordinate prices for tasks, materials, and other items into higher-level "parent" tasks, materials, and other items. A description of the task to be accomplished is generated for each element of the work breakdown structure. This method (also known as a system breakdown structure) is used to define and organize a project's overall scope. (Pritchard, 2019)

In project management and systems engineering, a work-breakdown structure (WBS) is a deliverable-oriented breakdown of a project into smaller components. A work breakdown structure is a critical project deliverable that divides the work of the team into manageable chunks.

The work-breakdown structure is defined by the Project Management Body of Knowledge (PMBOK 5) "A hierarchical decomposition of the complete scope of work to be performed by the project team in order to meet the project's objectives and produce the requisite deliverables." A product, data, service, or any combination of these can be a work-breakdown structure element. A WBS also provides the essential foundation for detailed cost estimation and control, as well as schedule development and control advice.

In a NASA reporting structure, an example of a work breakdown structure is used.The work breakdown structure is the foundation for dividing work into definable increments from which the statement of work can be developed and technical, schedule, cost, and labor hour reporting can be established. It also provides a common framework for the natural development of the overall planning and control of a contract. The WBS is usually created at the outset of a project and comes before thorough project and task planning. Instead of the work required to produce the products, the WBS is arranged around the project's key products (or expected results).(Pritchard, 2019)

1.5 Quantity take off

During the design process, many different sorts of estimations might be created. These range from rough estimates early in the design process to more exact estimates after the design is completed. Clearly, waiting until the conclusion of the design phase to produce a cost estimate is not a good idea. If the project goes over budget after the design phase, there are only two options: cancel it or use value engineering to save money and perhaps quality. Interim estimates help reveal difficulties early in the design process so that alternatives can be considered. This method enables the designer and owner to make better informed decisions, resulting in higher-quality construction while staying within budget. Interim estimates are much easier to produce with BIM.(John Wiley & Sons, 2011)

The only quantities accessible for estimation at the early design phase are those related to areas and volumes, such as types of space, perimeter lengths, and so on. These figures may be sufficient for a parametric cost estimate, which is generated using significant construction parameters. The parameters used vary depending on the building type, such as the designated parking areas and floors in a parking garage, the number and area of each type of commercial space, the number of floors, the quality level of materials used in a commercial building, the location of the building, the number of lifts, the area of the external walls, the area of the roof, and so on. (John Wiley & Sons, 2011)

Unfortunately, since these quantities do not specify object types, such as those established by a BIM design system, they are not commonly available in early schematic design. As a result, it's critical to convert the early design model to BIM software so that quantity extractions and cost estimations may be made. As the design progresses, more detailed spatial and material quantities can be extracted directly from the building model. (John Wiley & Sons, 2011)

All BIM systems allow you to extract component counts, space area and volume, and material amounts, as well as report them in numerous challenges. These quantities are more than sufficient for generating rough cost estimates. Problems may develop when component definitions (usually assemblies of parts) are not adequately defined and are incapable of extracting the quantities needed for cost estimating, resulting in more accurate cost estimates prepared by contractors. (John Wiley & Sons, 2011)

BIM software may, for example, provide the number of linear feet of concrete footings but not the amount of reinforcing steel contained in the concrete; or the area of interior partition walls but not the number of studs in the walls. These are challenges that can be solved, but the method will vary depending on the BIM program and accompanying estimating system used.

Accurate cost estimates can be established earlier in the design process if an IPD strategy is employed that allows general and trade contractors to engage during the design phase. Furthermore, contractor constructability knowledge can inform the design process, reducing model modifications and hence cost and time. (John Wiley & Sons, 2011)

It should be noted that while building models are useful for quantity takeoffs, they are not a substitute for estimating. Estimators play a vital function in the construction process that extends beyond counting and measuring. Estimating entails evaluating project conditions that have an impact on cost, such as uncommon wall conditions, unique assemblies, and difficult access.

It is currently not possible for any BIM tool to automatically identify these situations. Estimators should think about leveraging BIM technology to make the tedious work of quantity takeoff easier, as well as to quickly visualize, identify, and assess conditions, giving them more time to conduct constructability evaluations and negotiate better rates with subcontractors and suppliers. Because it decreases the uncertainty associated with material quantities, a thorough building model is a risk-mitigation tool for estimators that can significantly cut bid prices. (John Wiley & Sons, 2011)

The case studies of One Island East Office Tower and Sutter Medical Center in Chapter 9 are outstanding instances of this. Estimators employ a number of tools to support the estimating process and leverage BIM for quantity takeoff. Estimators must find a strategy that works best for their specific estimating process because no BIM product has all of the features of a spreadsheet or estimating application. There are three primary options:

1. Import the quantities of building objects into estimating software.

2. Connect the BIM tool to the estimating program directly.

3. Make use of a quantity takeoff tool for BIM.

Each of these choices is addressed in further depth further below.

1.5.1 Quantity Export to Estimating Software

Most software manufacturers' BIM solutions contain facilities for extracting and quantifying BIM component attributes, as previously mentioned. Tools for exporting quantity data to a spreadsheet or an external database are also included in these functionalities. There are over 100 commercial estimating packages in the United States alone, many of which are tailored to the sort of job being estimated. However, according to polls, MS Excel is the most widely utilized estimating tool (Sawyer and Grogan 2002).

The capacity to extract and associate quantity takeoff data using custom Excel spreadsheets is generally sufficient for many estimators. However, this strategy may necessitate a significant amount of setup and adoption of a consistent modeling process. One of the methods listed below is necessary to proceed beyond Excel.

1.5.2 Link BIM Components to Estimating Software Directly

The second option is to employ a BIM program with a plug-in or third-party application that can connect directly to an estimating package. Many of the biggest estimating software systems now have BIM tool plug-ins.For example, Timberline via Innovaya (Innovaya 2010); U.S. Cost (Success Design Exchange 2010, Success Estimator 2010); Nomitech (CostOS v3.6 BIM Estimating 2010); and Vico Estimator (Success Design Exchange 2010, Success Estimator 2010). (Vico 2010).

These features enable the estimator to link objects in a building model to assemblies, recipes, or items in the estimating package, as well as to an external cost database like R.S. Means. These assemblies or recipes specify the steps and resources required for onsite component building or prefabricated component erection or installation. Construction tasks like as place forms, place rebar, pour concrete, cure, and strip forms are frequently included in assemblies or recipes. The estimator can apply rules to his or her work. Calculate values based on component attributes or manually enter data not collected from the building information model for these components. Items representing necessary resources such as personnel, equipment, materials, and so forth, as well as associated time and cost expenditures, may be included in the assemblages.

As a result, all of the information needed to produce a thorough cost estimate and a detailed list of basic activities may be used to plan the building. This information can be utilized to produce a 4D model if it is related to BIM components. The estimate can also be linked to the graphic model to show the model objects associated with each line item inside that estimate.

This is incredibly useful for recognizing objects that don't have a price tag attached to them. For contractors that have standardized on a specific estimate program and BIM technology, this strategy works effectively. However, if different BIM systems are utilized, integrating BIM component information from subcontractors and diverse trades may be difficult to manage.

This fully integrated method has obvious advantages, but one potential drawback is the contractor's requirement to design a distinct model. Naturally, if the architect does not use BIM, a contractor model is required. When this isn't the case, it's more efficient for the designer's model to serve as the contractor's starting point after the team has agreed on component definitions. This strategy may be appropriate if the project team is standardized on a single software vendor platform.

This necessitates either a design-build strategy or a contract that includes all of the major project partners from the start (IPD). The keys to efficient use of BIM technology are, once again, early integration and collaboration.

1.5.3 Make use of a quantity takeoff calculator

A third option is to use a specific quantity takeoff tool that imports data from several BIM programs, as shown in Figure 51.

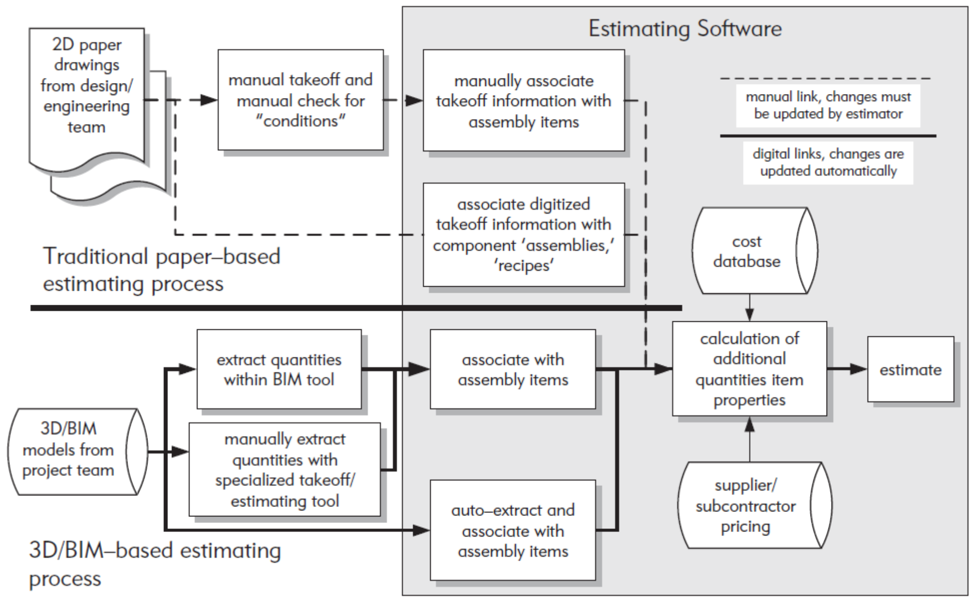


Figure 10: Conceptual diagram of a BIM quantity takeoff and estimating process

This enables estimators to use a takeoff tool that is specifically tailored to their needs rather than learning all of the features available in a given BIM package.

Autodesk QTO (QTO 2010), Exactal CostX® Version 3.01 (Exactal 2009), Innovaya (Innovaya 2010), and Vico Takeoff Manager are some examples. Specific capabilities that link directly to items and assemblies, annotate the model for "conditions," and build visual takeoff diagrams are common in these tools.

These programs provide varied amounts of automated extraction and manual takeoff support. To support the vast range of takeoff and condition checking that estimators must undertake, they will need to use a combination of manual tools and automation features.

Any new objects added to the building model must be linked to correct estimating jobs in order to obtain accurate cost estimates from the model, based on the accuracy and level of information currently there.

1.6 Cost estimation

In the preconstruction phase of a project, BIM-derived estimation (also known as 5D) has long been thought to be the "golden goose" of BIM. BIM-derived estimating, in theory, uses the database underpinning a building information model to provide an estimate by either directly linking model components to unit cost or cost assembly recipes.(Rogério dos Santos Alves; Alex Soares de Souza, 2014)

A model with 10,000 square feet of drywall, for example, would be linked to a unique cost formula that included information like crew size, hourly rates, material costs, and productivity rates. This allows the model to estimate how long it will take to install the materials that have been removed from it.

In essence, the timeline becomes a function of how much "stuff " you plan to construct in a specific order. This differs from prior techniques, in which the schedule and estimate were frequently treated as two separate files that were rarely linked.(Rogério dos Santos Alves; Alex Soares de Souza, 2014)

Building information models can become more integrated thanks to products like Trimble's Vico software, which eliminates the need to link various schedules to the model and instead incorporates both the building components (3D), schedule (4D), and cost (5D) information in one tool.(Rogério dos Santos Alves; Alex Soares de Souza, 2014)

In the preconstruction phase of a project, BIM-derived estimation (also known as 5D) has long been thought to be the "golden goose" of BIM. BIM-derived estimating, in theory, uses the database underpinning a building information model to provide an estimate by either directly linking model components to unit cost or cost assembly recipes.

A model with 10,000 square feet of drywall, for example, would be linked to a unique cost formula that included information like crew size, hourly rates, material costs, and productivity rates. This allows the model to estimate how long it will take to install the materials that have been removed from it. In essence, the timeline becomes a function of how much "things" you plan to construct in a specific order This differs from prior techniques, in which the schedule and estimate were frequently treated as two separate files that were rarely linked.(Rogério dos Santos Alves; Alex Soares de Souza, 2014)

1.7 Time analysis

Time planning is fundamental in the project management phase because it allows the concatenation between the various design phases, and the integration between all the active parties involved in the implementation of the project.

The most common techniques used for scheduling times are the following:

- The Time Schedule: for time scheduling based on the Gantt bar chart.
- The Critical Path Method (CPM), deterministic time estimates;
- The Program Evaluation and Review Technique (PERT), probabilistic time estimates

1.7.1 Gantt bar chart

Popescu and Charoenngam define a bar chart as a graphical depiction of project activities depicted as time scaled bar lines with no linkages between the bars (activities).

It is defined by PMI (PMI, 2013) as "a graphic display of schedule-related information."

Schedule activities or work breakdown structure components are listed down the left side of the chart, dates are indicated across the top, and activity durations are displayed as date-placed horizontal bars in a traditional bar chart." The bar chart, sometimes known as a Gantt chart, was created by an American mechanical engineer named Henry L. Gantt in 1917. (Mubarak, 2010). Because of its capacity to graphically describe a project's operations in a clear, straightforward, and time-scaled manner, it quickly became popular, particularly in the construction sector.

Before constructing a bar chart for a project, it must be split down into smaller, usually homogeneous components, which each of them referred to as an activity or task. There is no single "right" approach to divide down a project into activities, and we can't say that any of the strategies are incorrect.

The scheduler, on the other hand, should take a balanced approach and break down the project into a manageable number of activities that can be measured and controlled without being unduly complex.

An activity, or task, can be as large as establishing a building's foundation, as little as erecting the formwork for a single footing, or anywhere in between. As the next step each activity's time must be estimated. The duration of each action, as well as the beginning and finishing points, are then shown by bars.

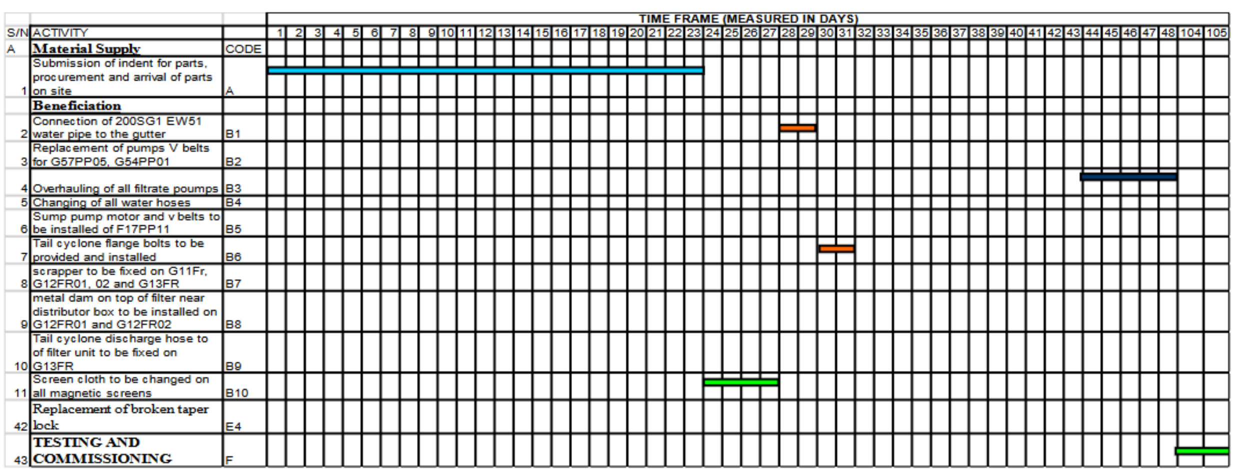


Figure 11: Gantt chart (Smith, 2014)

1.7.2 The Critical Path Method (CPM)

The Critical Path Method, translating the needs of a project into a mathematical system necessitates an awareness of the general stages in which CPM routines can be used: planning, scheduling, and controlling (more appropriately termed "monitoring" for research application). The largest benefit of CPM can be noticed during the planning stage.

The user is expected to think rationally and in sufficient detail about a project in order to generate firm, clear project objectives, activities, and specifications. This reduces the likelihood of a project's essential tasks and goals being overlooked. CPM provides a realistic and disciplined strategy for identifying how to achieve project objectives and expressing and documenting project plans clearly and concisely during the scheduling stage. A time chart is created to show the start and finish timeframes for each action, as well as the amount of "float" associated with each activity's link to other project activities. (Anderson Earl B. Hales, 1986)

The monitoring stage assists management in focusing their attention where it is most needed: on the activities that have the greatest impact on the timetable. CPM will generate revised schedules to accommodate operations that are performed ahead of or behind schedule, and as technical or procedural modifications are evaluated, CPM will highlight the impact these changes will have on the overall timetable. Three basic processes are carried out in the planning and scheduling phases of CPM analysis:

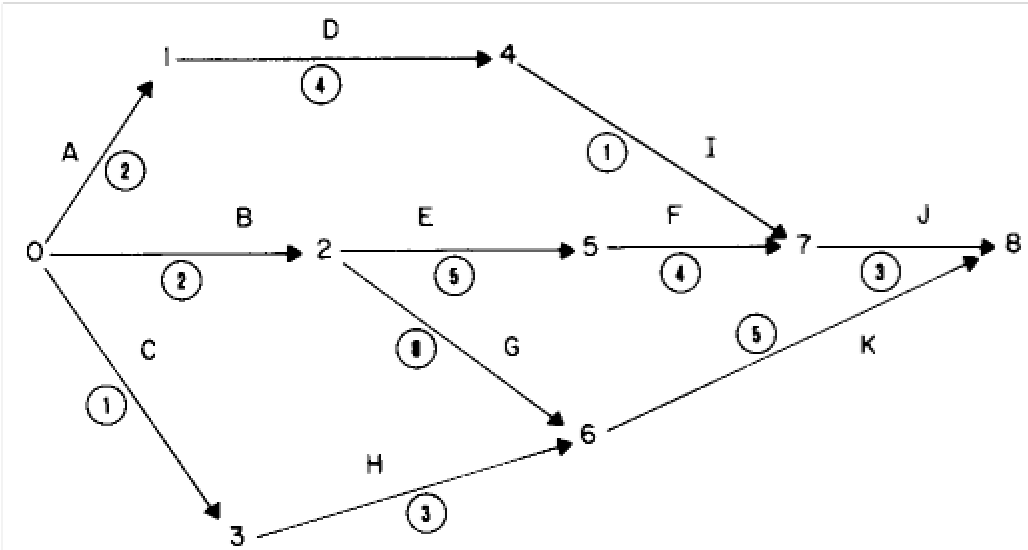


Figure 12: A project's network or arrow diagram depicts the sequence in which activities will be completed. Activities (capital letters) are represented by arrows, arrowheads show the order of activities, and nodes or points (numbers) mark the start and finish of activities. The numbers in the circles represent the durations of activities in time units. (Anderson Earl B. Hales, 1986)

1. Making a network diagram to show how activities are prioritized.
2. Determining the start, end, and slack or float times
3. Making a time chart to show the outcomes of step 1 and 2.(Anderson Earl B. Hales, 1986)

1.7.3 The Program Evaluation and Review Technique (PERT)

Since that time, the use of PERT has found useful applications in the manufacturing industry, government, construction work, research management, product development and information technology. Today, many firms and government agencies require that all skillful engineers use PERT in the completion time analysis of engineering projects (Lockyer and James, 2005). PERT is a network-based aid for planning and scheduling many interrelated tasks in a large and complex project. It was one of the most complex tasks ever attempted at the time of its emergence. Nowadays PERT techniques are routinely used in any large project such as software development, building construction, maintenance works, etc. (Chinneck, 2009).

A project is a collection of a significant number of operations or jobs that are executed in a logical or technologically determined sequence and must be completed within a particular time and cost while fulfilling performance requirements.

The project could be the creation of a software program, the construction of a house or an office building, the development of a new drug, a new product marketing campaign, and so on. Network models are a common approach of determining the most efficient way to connect a number of activities, either directly or indirectly, in order to meet supply and demand requirements at various activity locations and project timing.

The Critical Path Method (CPM) and the Project Evaluation and Review Technique have been demonstrated to be beneficial for planning, scheduling, and regulating construction projects for many years (PERT). Project managers can use these techniques to assess the earliest and latest times at which activities can begin and end, compute activity float (slack), determine important activities, and assess the impact of changes in length, logical relationships, and cost on the entire project duration. Both CPM and PERT are network-based techniques that aid in the programming and monitoring of the stages involved in ensuring that the project is completed on time.

This identifies the parts of the project that are critical and, if delayed beyond the normal period, will extend the project's overall completion time. It also aids in the allocation of resources such as manpower and equipment, lowering the overall cost of the construction project by determining the best trade-off between various expenses and time constraints.(Islam, 2021)

The purposes of the planning of the works are therefore summarized in:

✓ Subdivision into work packages

✓ Definition of control centers

✓ Estimates and definition of the budget and resources

The most used and most useful tool to carry out this phase of the decision-making process is the W.B.S (Work Breakdown Structure), which as already mentioned is a hierarchical deconstruction of the works developed in a tree.

An important factor in the creation of the WBS is the correct coding of each individual activity, this allows direct control and identification of the activity taken into consideration.

BIM and project management for optimal control of costs, project timing, quality and risks of the Building Information Management process

1.8 Energy efficiency in building

1.8.1 Energy performance of building in Europe

The Energy Performance of Buildings Directive (EPBD, 2002/91/EC), introduced in 2002 and amended in 2010 (EPBD recast, 2010/31/EU) with more ambitious rules, is the key policy driver relating to energy use in buildings at the European level. Energy regulation (e.g. building codes) and energy certification are the two primary mechanisms recognized to articulate the engagement of energy assessment in the building sector. Energy certification of buildings becomes mandatory in Member States under the EPBD, and so plays an important role in energy conservation . (Salvalai et al., 2015)

Mandatory rules for regulating energy use in buildings first appeared in the mid-1970s [24]. It is by far the most extensively used method of improving building energy efficiency, having been embraced by a vast number of European countries and regions. Increasing building energy performance is critical for securing the transition to a low-carbon economy and achieving the EU Climate and Energy goals, which include a 20% reduction in GHG emissions by 2020, a 20%

reduction in energy savings by 2020, and a 20% renewable energy share in EU gross final consumption by 2020. (Salvalai et al., 2015)

The European legislative framework for buildings has been evolving since the early 1990s, but it wasn't until the Directive on Energy Performance of Buildings that it really took off (EPBD). Several studies, for example, by Dascalacki et al. in Greece, Tronkin and Fabbri in Italy, Ekins and Lees in the United Kingdom, or Araùjo et al. in Portugal, have looked into its implementation in different European countries showing characteristics and potential in increasing energy efficiency. (Salvalai et al., 2015)

According to Andaloro et al. the Directive was adopted at various dates and with discrepancies between EMS, resulting in a fragmented situation even though there is a common frame. An examination of present constraints and instruments for improving energy efficiency in European buildings reveals considerable discrepancies in commitment, financial capability, and market conditions.(Salvalai et al., 2015)

This emphasizes the importance of moving away from the widely held paradigm of considering the aforementioned dimensions in an almost unrelated manner and toward a new paradigm that takes a holistic approach to building sustainability and implements all relevant aspects in a concise and efficient manner. (Kephalopoulos et al., 2017)

This multi-dimensional approach to building performance concerns an upfront definition and implementation of building sustainability, which was presented, discussed, and widely supported for the first time at EU level in the context of the European Forum for Science and Industry round table on scientific support to energy performance of buildings, which was organized by the European Commission's Joint Research Centre (JRC) on November 29, 2013 in Brussels44 and is graphing a holistic view of building sustainability, the first component of building performance considers and puts structural safety, stability, and durability into practice.

The Eurocodes 45 are a set of European Technical Standards for structural design of buildings, civil engineering works, and construction goods that have been well-consolidated and applied. Their development and execution began in the 1970s, when the European Communities Commission decided to adopt an action plan to gradually remove technical trade barriers in the building sector. (Kephalopoulos et al., 2017)

EN Eurocodes help to the creation and operation of an Internal Market for building products and services in this regard. They also ensure that construction safety in Europe is uniform. Building codes have been instrumental in reducing overall energy consumption of buildings in the EU over the last two decades, with the amount of energy savings depending on the stringency of energy requirements and the approach used in the design of building energy codes.

A prescriptive approach requires an integrated design and requirements set for the building's overall energy consumption (either minimum energy performance requirements based on the building's size or standard energy performance requirements for all building sizes), whereas a performance-based approach requires an integrated design and requirements set for the building's overall energy consumption (either minimum energy performance requirements based on the building's size or standard energy performance requirements for all building sizes).

In Europe, as part of the EPBD implementation, requirements have gradually shifted from prescriptive to performance-based, which is considered a significant movement in building code trends. In practice, single-element approaches are used in big renovation projects, whereas performance-based approaches are preferred in new builds, while a blended approach has been embraced by a number of EU MS. (Kephalopoulos et al., 2017)

In terms of the evolution of building energy codes, in addition to the aforementioned paradigm shift related to provisions aimed at improving energy performance, there is a new wave of codes (e.g. the French building energy code46) that address both energy performance and energy supply from renewable sources simultaneously and include corresponding requirements.

Energy sufficiency methods are designed to lower the amount of energy required to operate and maintain a structure. The orientation of the structure in relation to the sun, its form, volume, placement in relation to nearby buildings, and general daylight and sunshine requirements based on bio-climatic design principles are all examples of energy sufficiency measures.

Buildings can be changed from energy consumers to power generators capable of supplying electricity to the grid by integrating renewable energy sources into them. Renewable energy sources could potentially come from nearby buildings or be provided through district heating and cooling systems. The optimum method for establishing effective building codes from an energy standpoint is to combine energy sufficiency, energy efficiency, and supply from renewable energy sources. These are significant drivers for successfully reducing building related energy consumption patterns over time.

When the economic dimension of the holistic concept of building sustainability is added to the energy dimension, increasing the stringency of energy performance requirements in building codes (i.e. reaching the nearly zero-energy target by 2020) is an unavoidable consequence to secure long-term economic and energy security solutions. (Kephalopoulos et al., 2017)The EPBD already compels EU Member States to set minimum energy performance requirements for buildings in order to achieve cost-optimal levels, i.e. the level of energy performance that results in the lowest cost throughout the expected economic lifespan.

Building related embodied energy (i.e. the energy necessary to generate building materials and construct buildings) and usage patterns (i.e. how buildings are used by their occupants) are two other key variables to examine when it comes to the energy consumption of buildings. The ‘sustainability' facet of the holistic idea of building sustainability is represented by this. Indeed, a life-cycle analysis of existing low-energy buildings reveals that the share of embodied energy in total energy consumption of a low-energy building over its lifetime is substantially higher than that of an inefficient building (IEA/UNDP, 2013).

These two characteristics represent key drivers of a building's energy consumption over its entire lifespan, and they should be thoroughly examined with any other energy efficient, energy-sufficient, and renewable energy supply measures if an effective energy reduction policy is intended. The fundamental goal of sustainable buildings is to reduce the environmental effect of resources such as materials, water, and embodied energy throughout the life cycle of structures, from material extraction to demolition and material recycling. (Kephalopoulos et al., 2017)

Integrating this dimension into the holistic concept of building sustainability, as energy consumption in buildings is primarily intended to ensure conditions of well-being, comfort, and health for their occupants, creates the difficult task of reconciling energy savings ambitions with the obligation to ensure conditions of growing up, living, working, and learning in healthy indoor environments. This latter reflects a human right that the World Health Organization (WHO) explicitly affirmed in 2000. (WHO, 2000).

It should be highlighted that issues such as occupant health, comfort, and productivity as a result of indoor environmental quality have been incorporated in the context of the significant expanding of the definition of sustainability, particularly in the previous decade.

In addition to resource conservation, energy, water, and material resources, this expanded definition of sustainability includes assurances for mobility and access, as affected by land use and transportation, for health and productivity, as affected by indoor environmental quality, and for the preservation of regional strengths in the context of pursuing a more globally shared quality of life (Loftness et al., 2006; EC, 2014).

Sustainable buildings' occupants enjoy improved health and well-being, as well as increased productivity, which translates into cost savings (see also relevant numbers in the Box 'Setting the scene' above). The holistic concept of building sustainability, in terms of implementation, is a difficult task for building related policy makers, designers, managers, owners, and occupants, reflecting the complexity of a number of interconnected and interacting factors related to: the building itself and its systems (i.e. building's design, volume, orientation, openings, heating, ventilation, and air conditioning systems, lighting conditions, products and materials used); the long-term use of the building; and the long-term use of the building itself and its systems.(Kephalopoulos et al., 2017)

The overall idea of building sustainability should be considered in conjunction with the building's life cycle performance (Famuyibo et al., 2013).

To assist policymakers and designers in understanding the true national, regional, and global impacts of buildings on the environment, it is critical to fully account for and measure the energy use and emissions of a building throughout its life cycle, which includes all supply chain processes required for its production, operation, and removal.This will result in better decision-making.

This complication manifests itself in the interplay between indoor and outdoor air quality pollution sources, ventilation, thermal comfort, acoustic and lighting strategies, and energy sufficiency/efficiency/renewable energy supply measures, all of which should be conceptualized and implemented in an integrated manner in relation to major related policy objectives and instruments at EU MS levels (e.g. energy, environmentally and chemically based building labeling schemes, building in Concerns about building energy consumption and savings, as well as indoor air pollution as a significant factor in human health, arose in tandem over the last few decades, with the difficult issue being how to meet increased energy savings requirements (especially those associated with highly energy efficient and nearly zero-energy buildings) while maintaining indoor environments that are conducive to occupant comfort, health, and performance.(Kephalopoulos et al., 2017)

1.8.2 Energy performance of building in Italy

In Italy is in force the Ministerial Decree of 26 June 2015, which defines the minimum requirements for energy efficiency and energy needs in buildings, in compliance with Directive 2010/31 / EU. The Decree defines and regulates which are firstly, the minimum energy performances, drawn up during the design phase of the building .And secondly, the energy performance certification, drawn up upon completion of the building. Considering that the SMARTER project is aimed not only at new construction but also at renovation of existing buildings, the following is a list of the energy performances required and the related verifications for the specific types of intervention:

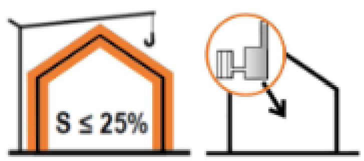
1. ENERGY REQUALIFICATIONS OF EXISTING BUILDINGS

2. SECOND LEVEL RENOVATIONS OF EXISTING BUILDINGS

3. NEW CONSTRUCTION or FIRST LEVEL RENOVATION OF EXISTING BUILDINGS (Green Building Council Italia, 2019)

1.8.2.1 ENERGY REQUALIFICATIONS OF EXISTING BUILDINGS

The "energy requalification of an existing building" include all the operation that have an impact on the energy performance of the building and that:



o involves an area less than or equal to 25% of the total gross dispersant surface of the building

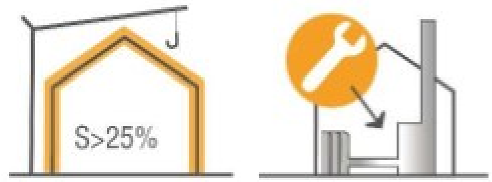
o consists in the new installation, or in the renovation of a thermal plant serving the building

In these cases, the required energy performance requirements is applied only to the building components and

installations subject to intervention, and refer to their relative thermo-physical or efficiency characteristics.

In particular, the following checks must be carried out on the structures of the enclosure and on the plants (Green Building Council Italia, 2019)

1.8.2.2 SECOND LEVEL RENOVATIONS OF EXISTING BUILDINGS



The "Second Level Renovations of existing buildings" is relative to building renovation that involve envelope with an incidence greater than 25% of the overall gross surface area of the building and may affect the heating system for the winter and / or air conditioning service for the summer. The verifications foreseen for this case study concern the performance check on the casing and/or on the plants based on the planned intervention. (Green Building Council Italia, 2019)

1.8.2.3 NEW CONSTRUCTION or FIRST LEVEL RENOVATION OF EXISTING BUILDINGS

The interventions contemplated in this case are:

o Construction of new buildings

o Demolition and reconstruction of existing buildings

o Extension of the gross volume > 15% of the existing gross heated volume

o Important first-level restructuring involving the building envelope with an incidence> 50% of the total gross building surface and the restructuring of the heating system for the winter and/or air conditioning service for summer serving the entire building.

Within these building interventions the same Decree (26 June 2015) also defines the NZEB3 for which it does not fix any absolute energy performance limit , but gives the indication that designer must implement and verify at once the respect of limit values for the thermo-physical characteristics and for the efficiency of the building and MEP components mandatory from 2021 (2019 for public buildings).

As previously mentioned for the SMARTER project it is useful to refer the analysis of energy requirements directly to these more restrictive limits that also correspond to what is required for the building to be defined as NZEB. (Green Building Council Italia, 2019)

1.8.2.4 Energy certification process

The energy class of a building is defined starting from the non-renewable global energy performance index:

$$EP_{gl,nren} = EP_{H,nren} + EP_{W,nren} + EP_{C,nren} + EP_{V,nren} + EP_{L,nren} + EP_{T,nren} \text{ [kWh/m}^2\text{ anno]}$$

Where:

EPH,nren: non-renewable primary energy requirement for winter heating and air conditioning;

EPW,nren: non-renewable primary energy requirement for hot sanitary water;

EPC,nren: non-renewable primary energy requirement for winter cooling and air conditioning;

EPV,nren: non-renewable primary energy requirement for ventilation;

EPL,nren: non-renewable primary energy requirement for artificial lighting; (not included for residential buildings)

EPT,nren: non-renewable primary energy requirement for the transport of people and things; (not included for residential buildings).

This index is the limit of separation between class A1 and B. To determine the overall energy class of the building, proceed as follows:

1. the value of EPgl-nren,rif,standard (2019-2021) is determined starting from the reference building ((also known as notional building) is a hypothetical building of the same design as the building of interest, with envelope assemblies and energy systems that meet a set of minimum prescriptive requirements), to which the reference values for the casing are set to 2019/2021 reported in DM 26/6/15 and assuming that the standard installations shown in the Table 1 are installed in the building using the parameters in force for the years 2019/21

Climatizzazione invernale	Generatore a combustibile gassoso (gas naturale) nel rispetto dei requisiti di cui alla tabella 8 dell'Appendice A all'Allegato 1 del DM requisiti minimi e con relativa efficienza dei sottosistemi di utilizzazione di cui alla tabella 7 della stessa Appendice.
Climatizzazione estiva	Macchina frigorifera a compressione di vapore a motore elettrico nel rispetto dei requisiti di cui alla tabella 8 dell'Appendice A all'Allegato 1 del DM requisiti minimi e con relativa efficienza dei sottosistemi di utilizzazione di cui alla tabella 7 della stessa Appendice.
Ventilazione	Ventilazione meccanica a semplice flusso per estrazione nel rispetto dei requisiti di cui alla tabella 9 dell'Appendice A all'Allegato 1 del DM requisiti minimi
Acqua calda sanitaria	Generatore a combustibile gassoso (gas naturale) nel rispetto dei requisiti di cui alla tabella 8 dell'Appendice A all'Allegato 1 del DM requisiti minimi e con relativa efficienza dei sottosistemi di utilizzazione di cui alla tabella 7 della stessa Appendice.
Illuminazione	Rispetto dei requisiti di cui al paragrafo 1.2.2 dell'Appendice A all'Allegato 1 del DM requisiti minimi.
Trasporto persone o cose	Rispetto dei requisiti al DM requisiti minimi.

Table 1: Technology standards for building refurbishment

2. the value of EPgl,nren is calculated for the building being certified

3. the energy class to be assigned based on the following table

	Classe A4	≤ 0,40 $EP_{gl,nren,rif,standard\ (2019/21)}$
0,40 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe A3**	≤ 0,60 $EP_{gl,nren,rif,standard\ (2019/21)}$
0,60 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe A2**	≤ 0,80 $EP_{gl,nren,rif,standard\ (2019/21)}$
0,80 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe A1**	≤ 1,00 $EP_{gl,nren,rif,standard\ (2019/21)}$
1,00 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe B**	≤ 1,20 $EP_{gl,nren,rif,standard\ (2019/21)}$
1,20 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe C**	≤ 1,50 $EP_{gl,nren,rif,standard\ (2019/21)}$
1,50 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe D**	≤ 2,00 $EP_{gl,nren,rif,standard\ (2019/21)}$
2,00 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe E**	≤ 2,60 $EP_{gl,nren,rif,standard\ (2019/21)}$
2,60 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	**Classe F**	≤ 3,50 $EP_{gl,nren,rif,standard\ (2019/21)}$
	Classe G	> 3,50 $EP_{gl,nren,rif,standard\ (2019/21)}$

Table 2: Classification of building based on energy consumption

In the Energy Performance Certificate of the building there are also other quality indicators regarding the winter and summer thermal performance of the building envelope assessed according to the minimum legal requirements. Note that the energy classification of the building is therefore not strictly correlated in an absolute sense to its energy needs but is determined as a function of the relationship between its energy needs and that of the reference building having the characteristics mentioned above. (Green Building Council Italia, 2019)

2 Case study project

This section is divided into two sections. The first case study focuses on constructing a work breakdown structure (WBS) to take off quantities (QTO) and finally arriving at an approximation of cost and time using Quantity take off softwares and Excel in the instance of a four-story residential building in Milan.

These two characteristics are also depicted in a Gant chart as a guide for demonstrating work progress using the Management software platform, which is described by BIM. This platform that is under development will help designers and constructor to manage the time, costs, activities and resources that are planned and involved in a project (https://www.BIM.it/bim-project-management-software).

In the second scenario, the same procedure was followed, but in this case, the same project is considered an ancient structure that must meet the upcoming energy efficiency standards set by law.

For the energy simulation, BIM software, Energy simulation software is used to first define the ancient building's energy consumption in its existing state and then after refurbishment.

2.1 Case study 1 : Demolition and new construction of the building

In the first case we assumed that building is time- worn so the decision was to Demolish the previous building and construct a new building 4-Story , residential Located in Milano, Italy.

The goal is to reach final timing and cost regarding to this case study. In this processes BIM tools were engaged to provide this estimation. As an overview the building was modeled in 3d modeling , then in order to take off the quantities, the pre-modeled building was imported to Quantity take off software. By accessibility to QTO and the unit of price and cost the Total time and cost was calculated in excel .

At the end the scheduling of construction in frame of Gant chart was possible to demonstrated by assistance of Management software platform introduced by BIM.

2.1.1 General information

The demand is for new construction building ,4-story residential, located of the building in Italy, Lomardia, commune di mialno in Via Vittore Buzzi street.

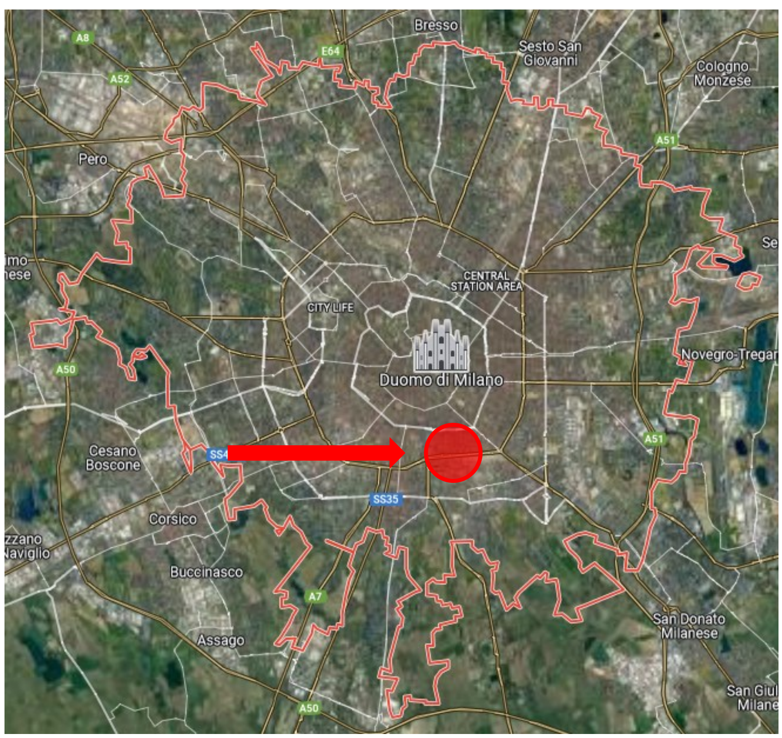


Figure 13: Location of the site in commune di Milano

Figure 14: Exact location of Site plan

In the following the plans of building are demonstrated in 2d from ground floor to roof plan.


21.30
2.27
1.58
1.56
1.50
1.60
1.50
0.77
1.50
1.45
1.18
1.57
1.45
1.50
1.88
11.20
Room
34 m²
Waiting room
22 m²
Reading room
41 m²
Storage
5 m²
Storage
2 m²
Room
3 m²
Room
22 m²
Technical room
10 m²
ELC room
3 m²
Shaft
3 m²
Corridor
3 m²
Corridor
2 m²
Bathroom
2 m²
Bathroom
5 m²
Room
20 m²
2.37
0.98
1.61
0.98
1.67
0.98
3.11
1.45
0.71
2.07
0.98
1.76
0.98
1.65

Figure 15: Ground level

Figure 16: 1st Floor plan

Figure 17: 2nd Floor plan

Figure 18: 3rd Floor plan

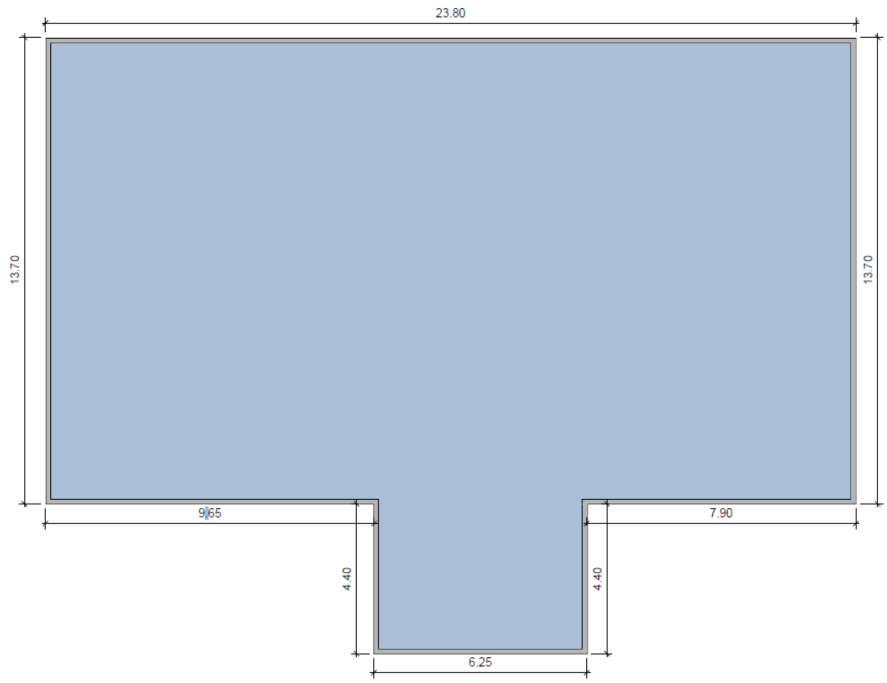


Figure 19: Roof plan

2.1.2 Progress of the project

In the following the model is done in 3d modeling based on the given information in 2d to pass through the first step of 3-dimensional information modeling.

Figure 20: 3d model in 3d modeling

In the next step the model is ready to import in Quantity take off softwares as chosen software for extracting Take off quantities.

In the preliminary stage we need to define work breakdown structure. WBS in this case is developed in 3 level , where first Level is concluded: preparation phase, structure execution and non-structural execution.

As the second level, the preparation phase is subdivided to Site preparation, Soil stabilization, foundation and landscape however, the structure execution and non-structure execution are categorized in to levels from ground to roof. Third level of breaking is shown as the table below.

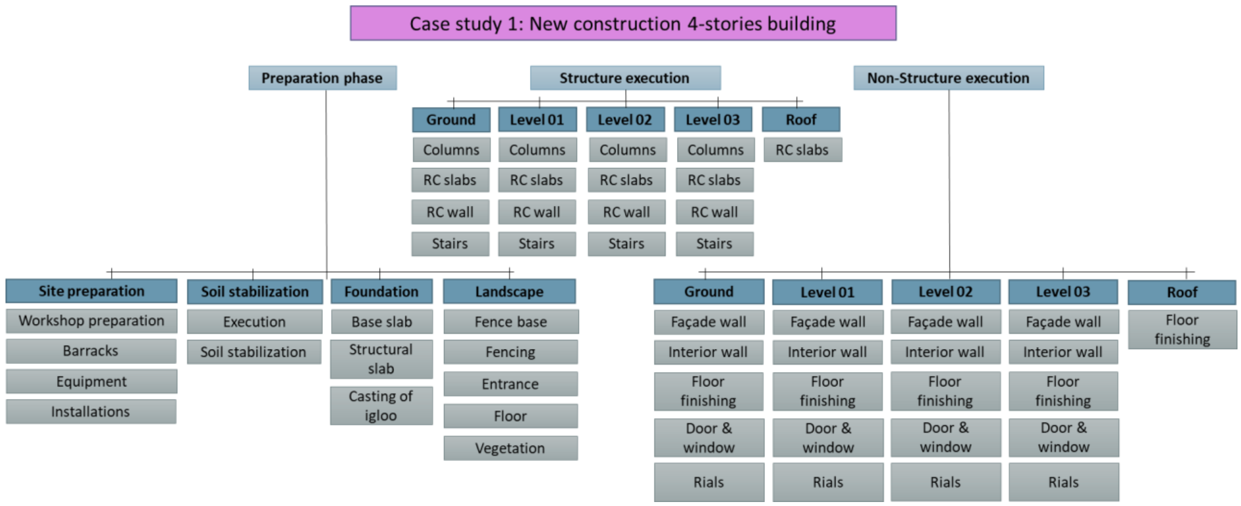


Figure 21: WBS for new construction 4 stories building

After providing WBS and insert the model in Quantity take off softwares, in order to reach to take off quantities, the tasks entered in item catalog based on provided WBS.

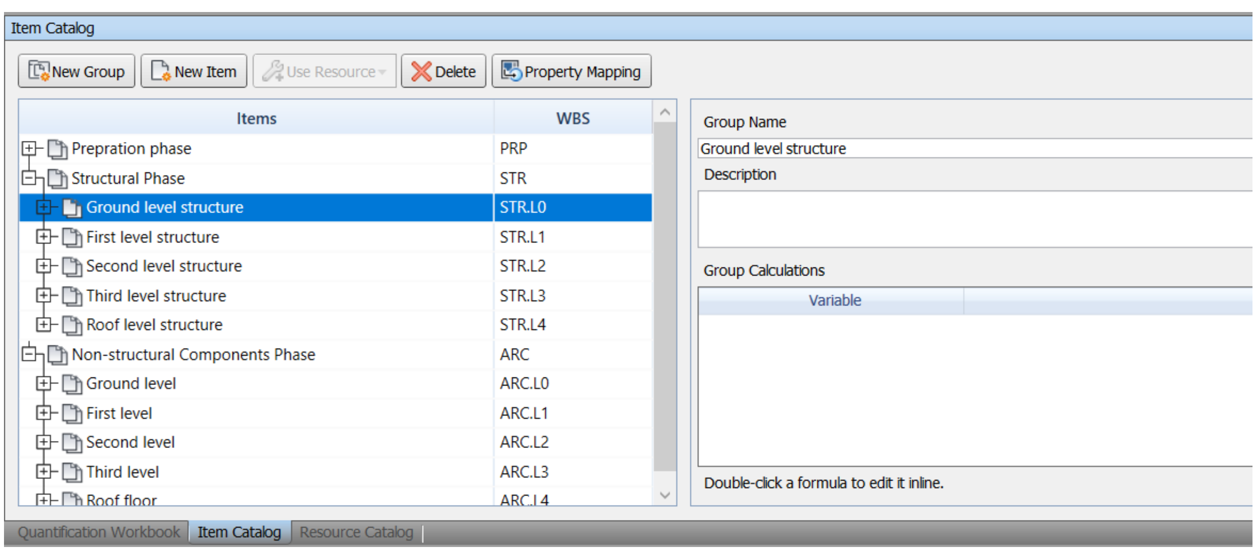


Figure 22: Item catalog for BIM software

In the resource catalog the demand unit of measurement of each sublayer was assigned

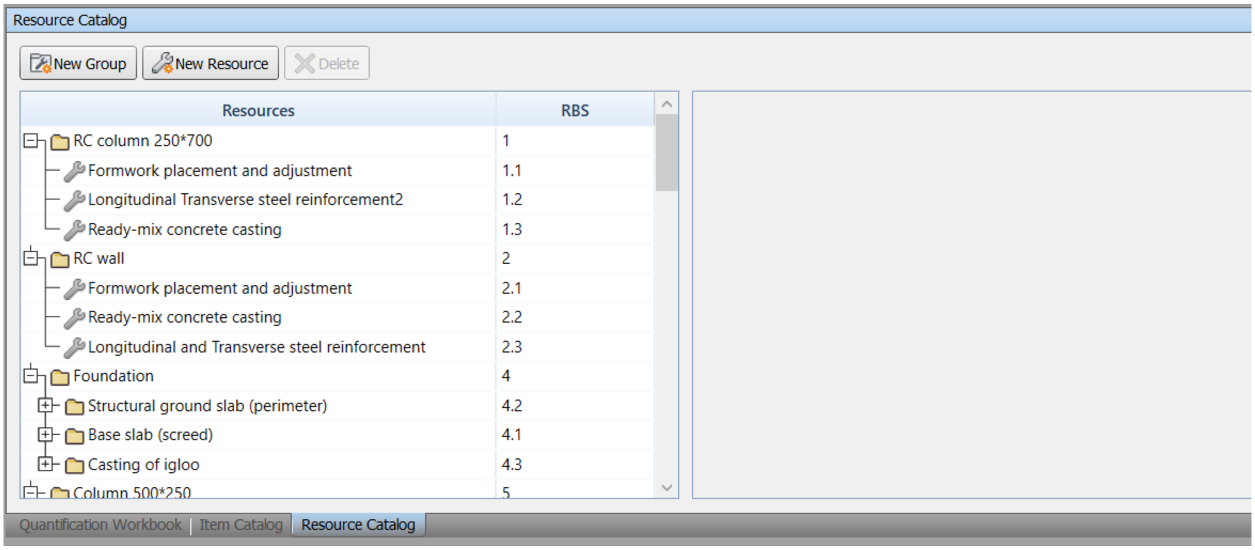


Figure 23: resources catalog for BIM software

At the following there are the rules and formulas used for the development of the QTO analysis within the Quantity take off softwares model.

On the model, in which is indicated, for the different structural elements, the specific theoretical percentage of reinforcement is exist for mass of steel per unit of volume concrete. In this way it was possible to use a single formula for all the different structural elements rather than having a different one for different elements. The theoretical values used for the reinforcement mass per volume unit for each structural element are shown below:

Reinforcement calculation	
Structural element	Steel mass per unit of volume (Kg/m3)
Shear wall	200
Beams	150

Pillars	150
Foundation	80
Slab	80
External balconies / floors	150
Stairs	150

Table 3: Formula for defining approximation steel in reinforcement

The formula which are based on for calculation of structural elements are shown at the following table. Since In some cases the demand quantity cant be extract directly, the replacement formula will enter directly in manual way.

Structural elements formula			
Tasks		Quantities	Formula
Formwork	Walls	Surface square meters	Height* Length
	Column	Surface square meters	Perimeter * Height
	Structural ground slab (perimeter)	Surface square meters	Perimeter * thickness
	Base slab (screed)	Surface square meters	Perimeter * thickness
	Casting of igloo	Surface square meters	Area
Reinforcement	Walls	200 kg of reinforcement per	200*volume

		cubic meter of casting	
	Column	150 kg of reinforcement per cubic meter of casting	150*volume
	Casting of igloo	80 kg of reinforcement per cubic meter of casting	80*volume
Concrete	Walls	Mc of cast concrete	Volume
	Column	Mc of cast concrete	Volume
	Structural ground slab (perimeter)	Mc of cast concrete	Volume
	Base slab (screed)	Mc of cast concrete	Volume
	Casting of igloo	Mc of cast concrete	=ModelArea*0.05

Table 4: formula for extracting take off quantities structural elements

Due to the inability to compute the area and volume values relating to the stairs since these parameters are not defined within the Quantity take off softwares software, it was necessary to compute these values manually using Excel software. The result shows that the formwork area of the ramp is equal to 15.03 m2 and the net volume of the staircase is equal to 2.01 m3.

Stairs	Formwork	15.03	m^2
	Armor	301.68	kg
	Concrete	2.11	m^3

Table 5: result for calculation of materials of stairs in each floor

In the following table the main formula for extracting take off quantities of Non-structural elements are represented.

Non-Structural elements formula			
Tasks		Quantities	Formula
Masonry laying	Masonry	Area of the wall	Area
Plastering	Partitions and Counter walls	Area	Area
	roof	Area including	Area
Membrane	Wall	Support area	Length * Height
	Roof	Support area	Area
Finishing	Floor	Attic area	Area
	External floor	Attic area	Area
	Roof covering	Attic area	Area
Doors and window	Door or window	Window area	Width * Height
	Door or window	Each	Count
Preframing	window	Window perimeter	Width +Height*2
	External doors	External perimeter	Width +Height*2
Vapor layer	Roof	Area of the roof	Area

Insulation	Floor	Area of the Floor	Area
	Wall	Area of the wall	Length * Height

Table 6: formula for extracting take off quantities structural elements

So after reaching to the Formula of each quantity, we can draw out the total quantity of for each layer corelated to wished unit of measurement. This formula will define in Resource catalog part in Quantity take off softwares , and it will assign in subcategory of each item catalog. As the last step in Quantity take off softwares we will assign model exported to each layer in quantification part in Navis and export result in excel.

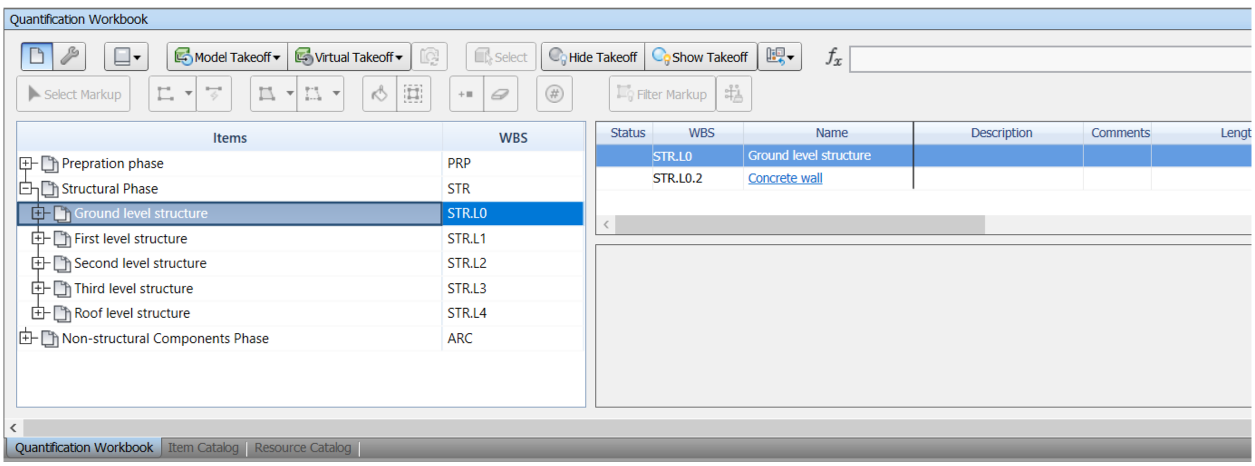


Table 7: Item catalog for BIM software

Since all the Quantities are measured by Quantity take off softwares as the next step, the unit of cost and time for each layer will be in demand. In the following, in order to reach this goal, we have to do a simple multiplication to record the total cost and time for each sublayer.

As its also represented in the following we will find the parameters of cost and time with respect to divisions of WBS.

First priority of new construction tasks is preparation of workshop, barracks, equipment and installation of Water and electricity facilities.

Id	Description	Quantity	Unit	Unitary Cost (Euros/unit)	Total Cost (Euros)	Unitary Duration (hrs/unit)	Total Duration (days)
Primilinary (PRP)							
PRP.1	Preparation						
P.1.1	Workshop preparation						
	assembly of gates	26.46	m2	98.46 €	€ 2,605.25	0.34 hrs	1.1 days
	fence assembly	151.00	m	7.60 €	€ 1,147.60	0.03 hrs	0.6 days
	signage assembly	4.00	-	20.13 €	€ 80.52	0.03 hrs	0.0 days
					€ 3,833.37		1.7 days
P.1.2	Barracks						
	positioning of office shacks	1.00	-	618.33 €	€ 618.33	1.98 hrs	0.2 days
	more office rental	12.00	Month	85.40 €	€ 1,024.80		33.0 days
	toilet positioning and rental	12.00	Month	260.00 €	€ 3,120.00		33.0 days
	positioning and rental of the working area roof	4.00	-	400.00 €	€ 1,600.00	1.71 hrs	0.9 days
					€ 6,363.13		33.0 days
P.1.3	Equipment						
	crane assembly	1.00	-	2,000.00 €	€ 2,000.00	1.70 hrs	0.2 days
	scaffolding assembly	819.86	m2	14.92 €	€ 15,934.56	0.04 hrs	4.1 days
	dismantling of the crane	1.00	-	2,000.00 €	€ 2,000.00	1.70 hrs	0.2 days
	dismantling of scaffolding	819.86	m2	14.92 €	€ 15,934.56	0.04 hrs	4.1 days
					€ 35,869.12		8.6 days
P.1.4	Installations						
	electrical system connection	1.00	-	3,500.00 €	€ 3,500.00	2.50 hrs	0.3 days
	more I use electricity	12.00	Month	150.00 €	€ 1,800.00		33.0 days
	water system connection	1.00	-	1,000.00 €	€ 1,000.00	1.70 hrs	0.2 days
	more water use	12.00	Month	250.00 €	€ 3,000.00		33.0 days
					€ 9,300.00		33.0 days

Figure 24: calculation of total cost and time for preliminary activities part A

After preparing of workshop and providing overriding facilities on site next step will be demolishing of the pervious building. Subsequently, as third level of preparation part we will with Excavation, preparation of the soil and resumption with foundation which is also divided to 3 subcategory.

PRP.2	Demolition of the previous building							
P.2	Demolition of the previous building		1068.00	m3	€ 6.84	€ 7,300.92	0.02 hrs	2.6 days
PRP.3	Excavation and soil stabilization							
P.3.1	Soil removal		349.50	m3	€ 5.40	€ 1,887.30	0.07 hrs	3.0 days
P.3.2	Retaining walls							
		Longitudinal and Transverse steel reinforcement	1167.00	kg	€ 0.89	€ 1,035.21	0.01 hrs	1.5 days
		Formwork placement and adjustment	133.49	m2	€ 41.89	€ 5,591.24	0.45 hrs	7.5 days
		Ready-mix concrete casting	9.73	m3	€ 148.66	€ 1,445.75	0.19 hrs	0.2 days
						€ 8,072.20		9.2 days
PRP.4	Foundations							
P.4.1	Base slab (scree	Ready-mix concrete casting - Poor	35.81	m3	€ 22.19	€ 794.67	0.15 hrs	0.7 days
P.4.2	Structural							
		Longitudinal and Transverse steel reinforcement	8771.70	kg	€ 1.20	€ 10,517.36	0.01 hrs	11.0 days
		Formwork placement and adjustment	70.92	m2	€ 51.00	€ 3,616.97	0.40 hrs	3.5 days
		Ready-mix concrete casting	109.65	m3	€ 147.50	€ 16,173.13	0.18 hrs	2.5 days
						€ 30,307.46		17.0 days
P.4.3	Casting of igloo							
		Electro-welded mesh	34061.20	kg	€ 1.20	€ 40,839.71	0.00 hrs	10.6 days
		Ready-mix concrete casting	6.53	m3	€ 22.19	€ 144.80	0.15 hrs	0.1 days
		IGLU C-45 modules	130.50	m2	€ 51.00	€ 6,655.32	0.31 hrs	5.1 days
						€ 47,639.83		15.8 days

Figure 25: calculation of total cost and time for preliminary activities part B

As the last part of Preparation, Landscape is placed which consist of flooring , vegetation and also entrance gate.

It should be consider that , however, structure start-up can be started in the same timing of landscape since they are not dependence tasks.

LND	Landscape							
LN.1	Entrance walls	Masonry	3.1338373	m2	€ 42.36	€ 132.74	0.50 hrs	0.2 days
LN.2	Entrance roof							
		Electro-welded mesh	926.17	kg	€ 1.20	€ 1,110.49	0.00 hrs	0.3 days
		Formwork placement and adjustment	30.57	m2	€ 45.72	€ 1,397.61	0.40 hrs	1.5 days
		Ready-mix concrete casting	6.17	m3	€ 139.38	€ 860.61	0.11 hrs	0.1 days
						€ 3,368.71		1.9 days
LN.3	Floor							
		Grass	597.15	m2	€ 19.90	€ 11,883.34		3.0 days
		Tiles	115.46	m2	€ 16.62	€ 1,919.03		5.0 days
		Asphalt	393.97	m2	€ 1.40	€ 551.56		5.0 days
						€ 14,353.93		5.0 days
LN.4	Vegetation							
		Romarino prostrato	19	-	€ 3.91	€ 74.29		1.0 days
		Albero dei coralli	1	-	€ 11.88	€ 11.88		2.0 days
		Albero selluva passa	1	-	€ 27.80	€ 27.80		2.0 days
		Asimina Triloba	1	-	€ 16.50	€ 16.50		2.0 days
						€ 130.47		2.0 days

Figure 26: calculation of total cost and time for preliminary activities part C

By ending of preparation of workshop and place all demand resources, equipment and etc, the tasks will continue with structural part.

The division of the work is for each floor, from ground to roof. Each level mainly separated by the means of tasks to reinforce pillars, slab, walls and sitars. All the values assign to the structure part for each level can be seen in the following tables.

	Structural Phase (STR)							
Id	Description		Quantity	Units	Unitary Cost (Euros/unit)	Total Cost (Euros)	Unitary Duration	Total Duration
STR.1	Ground level structure							
S.1.1	RC Pillars							
	0.25*0.5	Longitudinal and Transverse steel reinforcement	506.25	kg	€ 0.89	€ 449.08	0.01 hrs	0.6 days
		Formwork placement and adjustment	45.90	m2	€ 37.94	€ 1,741.60	0.45 hrs	2.6 days
		Ready-mix concrete casting	3.38	m3	€ 152.14	€ 513.48	0.22 hrs	0.1 days
	0.25*0.7	Longitudinal and Transverse steel reinforcement	315.00	kg	€ 0.89	€ 279.43	0.01 hrs	0.4 days
		Formwork placement and adjustment	25.84	m2	€ 37.94	€ 980.46	0.45 hrs	1.5 days
		Ready-mix concrete casting	2.10	m3	€ 152.14	€ 319.50	0.22 hrs	0.1 days
	Angular 0.25*0	Longitudinal and Transverse steel reinforcement	517.50	kg	€ 0.89	€ 459.06	0.01 hrs	0.6 days
		Formwork placement and adjustment	25.84	m2	€ 37.94	€ 980.46	0.45 hrs	1.5 days
		Ready-mix concrete casting	3.45	m3	€ 152.14	€ 524.89	0.22 hrs	0.1 days
						€ 6,247.94		7.4 days
S.1.2	RC Walls							
		Longitudinal and Transverse steel reinforcement	3298.93	kg	€ 0.89	€ 2,926.36	0.01 hrs	4.1 days
		Formwork placement and adjustment	178.20	m2	€ 41.89	€ 7,464.10	0.45 hrs	10.0 days
		Ready-mix concrete casting	16.49	m3	€ 148.66	€ 2,452.14	0.19 hrs	0.4 days
						€ 12,842.60		14.5 days
S.1.3	Stairs							
		Longitudinal and Transverse steel reinforcement	316.50	kg	€ 0.89	€ 280.76	0.01 hrs	0.4 days
		Formwork placement and adjustment	15.30	m2	€ 41.89	€ 640.84	0.45 hrs	0.9 days
		Ready-mix concrete casting	2.11	m3	€ 148.66	€ 313.68	0.19 hrs	0.1 days
						€ 1,235.28		1.3 days

Figure 27: calculation of total cost and time for structure phase ground floor

STR.2	First level structure							
S.2.1	RC Pillars							
	0.25*0.5	Longitudinal and Transverse steel reinforcement	496.13	kg	€ 0.89	€ 440.09	0.01 hrs	0.6 days
		Formwork placement and adjustment	70.47	m2	€ 37.94	€ 2,674.02	0.45 hrs	4.0 days
		Ready-mix concrete casting	3.31	m3	€ 152.14	€ 503.21	0.22 hrs	0.1 days
	0.25*0.7	Longitudinal and Transverse steel reinforcement	308.70	kg	€ 0.89	€ 273.84	0.01 hrs	0.4 days
		Formwork placement and adjustment	25.38	m2	€ 37.94	€ 963.15	0.45 hrs	1.4 days
		Ready-mix concrete casting	2.06	m3	€ 152.14	€ 313.11	0.22 hrs	0.1 days
	Angular 0.25*0	Longitudinal and Transverse steel reinforcement	507.15	kg	€ 0.89	€ 449.87	0.01 hrs	0.6 days
		Formwork placement and adjustment	25.38	m2	€ 37.94	€ 963.15	0.45 hrs	1.4 days
		Ready-mix concrete casting	3.38	m3	€ 152.14	€ 514.40	0.22 hrs	0.1 days
	0.25*.25	Longitudinal and Transverse steel reinforcement	125.25	kg	€ 0.89	€ 111.10	0.01 hrs	0.2 days
		Formwork placement and adjustment	13.36	m2	€ 37.94	€ 506.92	0.45 hrs	0.8 days
		Ready-mix concrete casting	0.84	m3	€ 152.14	€ 127.04	0.22 hrs	0.0 days
						€ 7,839.92		9.6 days
S.2.2	RC Walls							
		Longitudinal and Transverse steel reinforcement	1916.24	kg	€ 0.89	€ 1,699.83	0.01 hrs	2.4 days
		Formwork placement and adjustment	95.81	m2	€ 41.89	€ 4,013.10	0.45 hrs	5.4 days
		Ready-mix concrete casting	9.18	m3	€ 148.66	€ 1,364.93	0.19 hrs	0.2 days
						€ 7,077.85		8.0 days
S.2.3	RC Solid Slab							
		Electro-welded mesh	7553.78	kg	€ 1.20	€ 9,057.05	0.00 hrs	2.4 days
		Formwork placement and adjustment	236.97	m2	€ 45.72	€ 10,835.01	0.40 hrs	11.8 days
		Ready-mix concrete casting	91.86	m3	€ 139.38	€ 12,804.01	0.11 hrs	1.3 days
						€ 32,696.07		15.5 days
S.2.4	Stairs							
		Longitudinal and Transverse steel reinforcement	316.50	kg	€ 0.89	€ 280.76	0.01 hrs	0.4 days
		Formwork placement and adjustment	15.30	m2	€ 41.89	€ 640.84	0.45 hrs	0.9 days
		Ready-mix concrete casting	2.11	m3	€ 148.66	€ 313.68	0.19 hrs	0.1 days
						€ 1,235.28		1.3 days

Figure 28: calculation of total cost and time for structure phase first level

STR.3	Second level structure							
S.3.1	RC Pillars							
	0.25*0.5	Longitudinal and Transverse steel reinforcement	496.13	kg	€ 0.89	€ 440.09	0.01 hrs	0.6 days
		Formwork placement and adjustment	45.09	m2	€ 37.94	€ 1,710.86	0.45 hrs	2.5 days
		Ready-mix concrete casting	3.31	m3	€ 152.14	€ 503.21	0.22 hrs	0.1 days
	0.25*0.7	Longitudinal and Transverse steel reinforcement	308.70	kg	€ 0.89	€ 273.84	0.01 hrs	0.4 days
		Formwork placement and adjustment	25.38	m2	€ 37.94	€ 963.15	0.45 hrs	1.4 days
		Ready-mix concrete casting	2.06	m3	€ 152.14	€ 313.11	0.22 hrs	0.1 days
	Angular 0.25*0	Longitudinal and Transverse steel reinforcement	507.15	kg	€ 0.89	€ 449.87	0.01 hrs	0.6 days
		Formwork placement and adjustment	25.38	m2	€ 37.94	€ 963.15	0.45 hrs	1.4 days
		Ready-mix concrete casting	3.38	m3	€ 152.14	€ 514.40	0.22 hrs	0.1 days
	0.25*.25	Longitudinal and Transverse steel reinforcement	125.25	kg	€ 0.89	€ 111.10	0.01 hrs	0.2 days
		Formwork placement and adjustment	13.36	m2	€ 37.94	€ 506.92	0.45 hrs	0.8 days
		Ready-mix concrete casting	0.84	m3	€ 152.14	€ 127.04	0.22 hrs	0.0 days
						€ 6,876.76		8.2 days
S.3.2	RC Walls							
		Longitudinal and Transverse steel reinforcement	2104.40	kg	€ 0.89	€ 1,866.74	0.01 hrs	2.6 days
		Formwork placement and adjustment	65.41	m2	€ 41.89	€ 2,739.83	0.45 hrs	3.7 days
		Ready-mix concrete casting	10.52	m3	€ 148.66	€ 1,564.23	0.19 hrs	0.2 days
						€ 6,170.79		6.6 days
S.3.3	RC Solid Slab							
		Electro-welded mesh	7553.78	kg	€ 1.20	€ 9,057.05	0.00 hrs	2.4 days
		Formwork placement and adjustment	236.97	m2	€ 45.72	€ 10,835.01	0.40 hrs	11.8 days
		Ready-mix concrete casting	93.97	m3	€ 139.38	€ 13,098.10	0.11 hrs	1.3 days
						€ 32,990.17		15.5 days
S.3.4	Stairs							
		Longitudinal and Transverse steel reinforcement	316.50	kg	€ 0.89	€ 280.76	0.01 hrs	0.4 days
		Formwork placement and adjustment	15.30	m2	€ 41.89	€ 640.84	0.45 hrs	0.9 days
		Ready-mix concrete casting	2.11	m3	€ 148.66	€ 313.68	0.19 hrs	0.1 days
						€ 1,235.28		1.3 days

Figure 29: calculation of total cost and time for structure phase second level

STR.4	Third level structure							
S.4.1	RC Pillars							
	0.25*0.5	Longitudinal and Transverse steel reinforcement	489.38	kg	€ 0.89	€ 434.11	0.01 hrs	0.6 days
		Formwork placement and adjustment	44.55	m2	€ 37.94	€ 1,690.37	0.45 hrs	2.5 days
		Ready-mix concrete casting	3.26	m3	€ 152.14	€ 496.37	0.22 hrs	0.1 days
	0.25*0.7	Longitudinal and Transverse steel reinforcement	304.50	kg	€ 0.89	€ 270.11	0.01 hrs	0.4 days
		Formwork placement and adjustment	25.08	m2	€ 37.94	€ 951.62	0.45 hrs	1.4 days
		Ready-mix concrete casting	2.03	m3	€ 152.14	€ 308.85	0.22 hrs	0.1 days
	Angular 0.25*0	Longitudinal and Transverse steel reinforcement	500.25	kg	€ 0.89	€ 443.75	0.01 hrs	0.6 days
		Formwork placement and adjustment	25.08	m2	€ 37.94	€ 951.62	0.45 hrs	1.4 days
		Ready-mix concrete casting	3.34	m3	€ 152.14	€ 507.40	0.22 hrs	0.1 days
	0.25*.25	Longitudinal and Transverse steel reinforcement	116.30	kg	€ 0.89	€ 103.16	0.01 hrs	0.1 days
		Formwork placement and adjustment	12.41	m2	€ 41.89	€ 519.59	0.45 hrs	0.7 days
		Ready-mix concrete casting	0.78	m3	€ 148.66	€ 115.26	0.19 hrs	0.0 days
						€ 6,792.22		8.0 days
S.4.2	RC Walls							
		Longitudinal and Transverse steel reinforcement	2074.50	kg	€ 0.89	€ 1,840.22	0.01 hrs	2.6 days
		Formwork placement and adjustment	103.73	m2	€ 41.89	€ 4,344.55	0.45 hrs	5.8 days
		Ready-mix concrete casting	10.37	m3	€ 148.66	€ 1,542.01	0.19 hrs	0.2 days
						€ 7,726.77		8.7 days
S.4.3	RC Solid Slab							
		Electro-welded mesh	7553.78	kg	€ 1.20	€ 9,057.05	0.00 hrs	2.4 days
		Formwork placement and adjustment	236.97	m2	€ 45.72	€ 10,835.01	0.40 hrs	11.8 days
		Ready-mix concrete casting	91.86	m3	€ 139.38	€ 12,804.01	0.11 hrs	1.3 days
						€ 32,696.07		15.5 days
STR.5	Roof level structure							
S.5.1	RC Solid Slab							
		Electro-welded mesh	7633.70	kg	€ 1.20	€ 9,152.88	0.00 hrs	2.4 days
		Formwork placement and adjustment	238.55	m2	€ 45.72	€ 10,907.41	0.40 hrs	11.9 days
		Ready-mix concrete casting	95.42	m3	€ 139.38	€ 13,300.03	0.11 hrs	1.3 days
						€ 33,360.31		15.6 days

Figure 30: calculation of total cost and time for structure phase roof level

After finishing structure part, we will be beginning with non-structural elements time and cost estimation. Each level concluding: wall (internal and external), floor finishing (internal and external), closure elements and final touches and it finally reach to roof insulation and finishing.

As the last items that are under estimation is mechanical system concluded elevator, boiler and chiller for providing the heating and cooling load for the building.

	Non-structural Components Phase (ARC)							
Id	Description		Quantity	Units	Unitary Cost (Euros/unit)	Total Cost (Euros)	Unitary Duration	Total Duration
ARC.4	Roof insulation and finishing							
10.1	Masonry Curb		341.07	m2	€ 42.36	€ 1,082.24	0.50 hrs	21.3 days
10.2	Vapor layer		341.07	m2	€ 13.57	€ 4,076.39	0.10 hrs	4.3 days
10.3	Insulation Layer		341.07	m2	€ 40.91	€ 12,283.95	0.08 hrs	2.8 days
10.4	Water-resistant membrane		341.07	m2	€ 27.00	€ 8,400.44	0.10 hrs	3.9 days
						€ 25,843.01		32.3 days
ARC.0	Ground level							
A.0.1	External walls -							
A.0.1.1	Masonry	*Hollowbricks (cm 30x20x15) linked with mortar*	28.00	m2	€ 42.36	€ 1,186.04	0.50 hrs	1.8 days
A.0.1.2	Preframing for		12.48	m	€ 9.75	€ 121.67	0.10 hrs	0.2 days
A.0.1.3	Preframing for		51.22	m	€ 12.46	€ 638.16	0.13 hrs	0.8 days
A.0.1.4	Sills for		10.25	m	€ 16.71	€ 171.28	0.10 hrs	0.1 days
A.0.1.4.1		15 cm Exterior Coat Insulation	178.84	m2	€ 29.19	€ 5,219.59	0.12 hrs	2.7 days
A.0.1.4.2		7,5 cm Exterior Coat Insulation (only around	4.59	m2	€ 18.63	€ 85.45	0.12 hrs	0.1 days
						€ 7,422.19		5.6 days
A.0.2	Interior walls							
A.0.2.8	I.W. 15cm	*4 plasterboards (t:1.25cm) and aluminum*	280.25	m2	€ 44.15	€ 12,372.58	0.25 hrs	8.8 days
A.0.2.13	Preframing for		53.40	m	€ 9.75	€ 520.59	0.10 hrs	0.7 days
						€ 12,893.17		9.4 days
A.0.3	Floor finishing							
A.0.3.1	Interior Floor Finishing							
A.0.3.1.1		Screed - Light Mortar bedding layer *screed*	200.94	m2	€ 15.85	€ 3,184.17	0.25 hrs	6.3 days
A.0.3.1.2		Screed: Mortar bedding layer + Heating	200.94	m2	€ 37.42	€ 7,520.26	0.37 hrs	9.3 days
A.0.3.1.3		Flooring type 3 *Wooden Laminate Finishing*	200.94	m2	€ 27.29	€ 5,483.96	0.18 hrs	4.5 days
A.0.3.1.4		Insulation Layer *Ground Floor*	200.94	m2	€ 22.85	€ 4,591.52	0.08 hrs	1.9 days
A.0.3.2	Exterior Ground Floor Finishing					€ 20,779.91		22.0 days
A.0.3.2.1		Screed *(Exterior Ground Floor)*	115.46	m2	€ 39.58	€ 4,569.67	0.50 hrs	7.2 days
A.0.3.2.2		Waterproof Membrane	115.46	m2	€ 27.00	€ 3,117.61	0.10 hrs	1.4 days
A.0.3.2.3		Type4: Floor Finishing for Exteriors	115.46	m2	€ 29.72	€ 3,431.33	0.35 hrs	5.1 days
						€ 11,118.61		13.7 days
A.0.4	Closure elements							
A.0.4.1	Window Type1: 150x240cm		5.00	Unit	€ 308.83	€ 1,544.17	1.39 hrs	0.9 days
A.0.4.2	Window Type4: 90x90cm		5.00	Unit	€ 147.62	€ 738.11	0.31 hrs	0.2 days
A.0.4.3	Exterior door Type1: 90x210		1.00	Unit	€ 523.39	€ 523.39	1.20 hrs	0.2 days
A.0.4.4	Interior sliding door Type1: 90x210		2.00	Unit	€ 379.08	€ 758.16	1.40 hrs	0.4 days
A.0.4.5	Interior sliding door Type2: 80x210		2.00	Unit	€ 338.28	€ 676.56	1.40 hrs	0.4 days
A.0.4.6	Interior swinging door Type1: 90x210		4.00	Unit	€ 343.96	€ 1,375.82	1.20 hrs	0.6 days
A.0.4.7	Interior swinging door Type2: 80x210		1.00	Unit	€ 343.96	€ 343.96	1.20 hrs	0.2 days
						€ 5,960.17		2.7 days
A.0.5	Final Touches							
A.0.5.1	Plaster for Interiors		560.51	m2	€ 21.20	€ 11,882.20	0.37 hrs	25.9 days
A.0.5.2	Interior Painting (water-based)		487.65	m2	€ 7.79	€ 3,799.91	0.10 hrs	6.1 days
A.0.5.3	Interior Paintin	*Bathroom*	72.86	m2	€ 9.40	€ 684.78	0.10 hrs	0.9 days
						€ 16,366.89		32.9 days

Figure 31: calculation of total cost and time for non-structure phase roof and ground level

ARC.1	First level							
A.1.1	External walls - facades							
A.1.1.1	Masonry	*Hollowbricks (cm 30x20x15) linked with mortar*	193.90	m2	€ 42.36	€ 8,213.50	0.50 hrs	12.1 days
A.1.1.2	Preframing for		6.00	m	€ 9.75	€ 58.49	0.10 hrs	0.1 days
A.1.1.3	Preframing for		76.10	m	€ 12.46	€ 948.15	0.13 hrs	1.2 days
A.1.1.4	Sills for		16.05	m	€ 16.71	€ 268.20	0.10 hrs	0.2 days
A.1.1.4.1		15 cm Exterior Coat Insulation	176.13	m2	€ 29.19	€ 5,140.42	0.12 hrs	2.6 days
A.1.1.4.2		7,5 cm Exterior Coat Insulation (only around	2.34	m2	€ 18.63	€ 43.53	0.12 hrs	0.0 days
						€ 14,672.29		16.3 days
A.1.2	Interior walls							
A.1.2.1	I.W. 15cm	*4 plasterboards (t:1.25cm) and aluminum*	159.08	m2	€ 44.15	€ 7,023.02	0.25 hrs	5.0 days
A.1.2.2	Preframing for		83.70	m	€ 9.75	€ 815.97	0.10 hrs	1.0 days
						€ 7,839.00		6.0 days
A.1.3	Floor finishing							
A.1.3.1	Interior Floor Fi	Screed - Light Mortar bedding layer	200.38	m2	€ 16.29	€ 3,263.62	0.25 hrs	6.3 days
A.1.3.1.1		Screed - Heavy Mortar bedding layer + heating	200.38	m2	€ 37.42	€ 7,499.20	0.37 hrs	9.3 days
A.1.3.1.2		Flooring type 3 *Wooden Laminate Finishing*	200.38	m2	€ 27.29	€ 5,468.60	0.18 hrs	4.5 days
						€ 16,231.42		35.0 days
A.1.3.2	Exterior Floor Fi	Screed - Light Mortar bedding layer *only*	14.63	m2	€ 33.07	€ 483.98	0.45 hrs	0.8 days
A.1.3.2.1		Water-resistant membrane *(for the balconies)*	14.63	m2	€ 27.00	€ 395.10	0.10 hrs	0.2 days
A.1.3.2.2		Type4: Floor Finishing for Exteriors	14.63	m2	€ 29.72	€ 434.86	0.35 hrs	0.6 days
						€ 1,313.94		1.6 days
A.1.4	Closure elements							
A.1.4.1	Window Type1: 150x240cm		7.00	Unit	€ 308.83	€ 2,161.84	1.39 hrs	1.2 days
A.1.4.2	Window Type2: 275x240cm		1.00	Unit	€ 508.56	€ 508.56	2.54 hrs	0.3 days
A.1.4.3	Window Type3: 140x140cm		2.00	Unit	€ 238.66	€ 477.32	0.75 hrs	0.2 days
A.1.4.4	Window Type4: 90x90cm		0.00	Unit	€ 147.62	€ 0.00	0.31 hrs	0.0 days
A.1.4.5	Exterior door Type1: 90x210		1.00	Unit	€ 523.39	€ 523.39	1.20 hrs	0.2 days
A.1.4.6	Interior sliding door Type1: 90x210		3.00	Unit	€ 379.08	€ 1,137.24	1.40 hrs	0.5 days
A.1.4.7	Interior swinging door Type1: 90x210		10.00	Unit	€ 343.96	€ 3,439.56	1.20 hrs	1.5 days
						€ 8,247.92		3.9 days
A.1.5	Final Touches							
A.1.5.1	Plaster for Interiors		400.76	m2	€ 21.20	€ 8,495.79	0.37 hrs	18.5 days
A.1.5.2	Interior Painting (water-based)		298.80	m2	€ 7.79	€ 2,328.38	0.10 hrs	3.7 days
A.1.5.3	Interior Paintinք	*Bathroom*	101.96	m2	€ 9.40	€ 958.26	0.10 hrs	1.3 days
						€ 11,782.43		23.5 days

Figure 32: calculation of total cost and time for non-structure phase roof and first level

ARC.2	Second level							
A.2.1	External walls - facades							
A.2.1.1	Masonry	*Hollowbricks (cm 30x20x15) linked with mortar*	119.69	m2	€ 42.36	€ 5,070.06	0.50 hrs	7.5 days
A.2.1.2	Preframing for		6.00	m	€ 9.75	€ 58.49	0.10 hrs	0.1 days
A.2.1.3	Preframing for		77.20	m	€ 12.46	€ 961.85	0.13 hrs	1.3 days
A.2.1.4	Sills for		15.70	m	€ 16.71	€ 262.35	0.10 hrs	0.2 days
A.2.1.4.1		15 cm Exterior Coat Insulation	302.78	m2	€ 29.19	€ 8,837.09	0.12 hrs	4.5 days
A.2.1.4.2		7,5 cm Exterior Coat Insulation (only around	2.81	m2	€ 18.63	€ 52.26	0.12 hrs	0.0 days
						€ 15,242.11		13.6 days
A.2.2	Interior walls							
A.2.2.1	I.W. 15cm	*4 plasterboards (t:1.25cm) and aluminum*	119.69	m2	€ 44.15	€ 5,284.24	0.25 hrs	3.7 days
A.2.2.2	Preframing for		99.40	m	€ 9.75	€ 969.03	0.10 hrs	1.2 days
						€ 6,253.27		5.0 days
A.2.3	Floor finishing							
A.2.3.1	Interior Floor Fi	Screed - Light Mortar bedding layer	199.86	m2	€ 16.29	€ 3,255.06	0.25 hrs	6.2 days
A.2.3.1.1		Screed - Heavy Mortar bedding layer + heating	199.86	m2	€ 37.42	€ 7,479.52	0.37 hrs	9.2 days
A.2.3.1.2		Flooring type 3 *Wooden Laminate Finishing*	199.86	m2	€ 27.29	€ 5,454.25	0.18 hrs	4.5 days
						€ 16,188.83		20.0 days
A.2.3.2	Exterior Floor Fi	Screed - Light Mortar bedding layer *only*	14.63	m2	€ 33.07	€ 483.98	0.45 hrs	0.8 days
A.2.3.2.1		Water-resistant membrane *(for the balconies)*	14.63	m2	€ 27.00	€ 395.10	0.10 hrs	0.2 days
A.2.3.2.2		Type4: Floor Finishing for Exteriors	14.63	m2	€ 29.72	€ 434.86	0.35 hrs	0.6 days
						€ 1,313.94		1.6 days
A.2.4	Closure elements							
A.2.4.1	Window Type1: 150x240cm		7.00	Unit	€ 308.83	€ 2,161.84	1.39 hrs	1.2 days
A.2.4.2	Window Type2: 275x240cm		1.00	Unit	€ 508.56	€ 508.56	2.54 hrs	0.3 days
A.2.4.3	Window Type3: 140x140cm		2.00	Unit	€ 238.66	€ 477.32	0.75 hrs	0.2 days
A.2.4.4	Window Type4: 90x90cm		1.00	Unit	€ 147.62	€ 147.62	0.31 hrs	0.0 days
A.2.4.5	Exterior door Type1: 90x210		1.00	Unit	€ 523.39	€ 523.39	1.20 hrs	0.2 days
A.2.4.6	Interior sliding door Type1: 90x210		10.00	Unit	€ 379.08	€ 3,790.80	1.40 hrs	1.8 days
A.2.4.7	Interior swinging door Type1: 90x210		10.00	Unit	€ 343.96	€ 3,439.56	1.20 hrs	1.5 days
A.2.4.8	Interior swinging door Type2: 80x210		1.00	Unit	€ 343.96	€ 343.96	1.20 hrs	0.2 days
						€ 11,393.05		5.3 days
A.2.5	Final Touches							
A.2.5.1	Plaster for Interiors		525.72	m2	€ 21.20	€ 11,144.75	0.37 hrs	24.3 days
A.2.5.2	Interior Painting (water-based)		400.43	m2	€ 7.79	€ 3,120.27	0.10 hrs	5.0 days
A.2.5.3	Interior Painting	*Bathroom*	125.29	m2	€ 9.40	€ 1,177.54	0.10 hrs	1.6 days
						€ 15,442.56		30.9 days

Figure 33: calculation of total cost and time for non-structure phase roof and second level

ARC.3	Third level							
A.3.1	External walls - facades							
A.3.2	Masonry	*Hollowbricks (cm 30x20x15) linked with mortar*	99.08	m2	€ 42.36	€ 4,196.94	0.50 hrs	6.2 days
A.3.3	Preframing for		6.00	m	€ 9.75	€ 58.49	0.10 hrs	0.1 days
A.3.4	Preframing for		77.20	m	€ 12.46	€ 961.85	0.13 hrs	1.3 days
A.3.5	Sills for		15.70	m	€ 16.71	€ 262.35	0.10 hrs	0.2 days
A.3.6.1		15 cm Exterior Coat Insulation	149.14	m2	€ 29.19	€ 4,352.73	0.12 hrs	2.2 days
A.3.6.2		7,5 cm Exterior Coat Insulation (only around	3.25	m2	€ 18.63	€ 60.48	0.12 hrs	0.0 days
						€ 9,892.85		10.0 days
A.3.2	Interior walls							
A.3.2.1	I.W. 15cm	*4 plasterboards (t:1.25cm) and aluminum*	223.97	m2	€ 44.15	€ 9,887.71	0.25 hrs	7.0 days
A.3.2.2	Preframing for		99.40	m	€ 9.75	€ 969.03	0.10 hrs	1.2 days
						€ 10,856.74		8.2 days
A.3.3	Floor finishing							
A.3.3.1	Interior Floor Fi	Screed - Light Mortar bedding layer	199.08	m2	€ 16.29	€ 3,242.45	0.25 hrs	6.2 days
		Screed - Heavy Mortar bedding layer + heating	199.08	m2	€ 37.42	€ 7,450.54	0.37 hrs	9.2 days
		Flooring type 3 *Wooden Laminate Finishing*	199.08	m2	€ 27.29	€ 5,433.12	0.18 hrs	4.5 days
						€ 16,126.11		19.9 days
A.3.3.2	Exterior Floor Fi	Screed - Light Mortar bedding layer *only*	14.63	m2	€ 33.07	€ 483.98	0.45 hrs	0.8 days
		Water-resistant membrane *(for the balconies)*	14.63	m2	€ 27.00	€ 395.10	0.10 hrs	0.2 days
		Type4: Floor Finishing for Exteriors	14.63	m2	€ 29.72	€ 434.86	0.35 hrs	0.6 days
						€ 1,313.94		1.6 days
A.3.4	Closure elements							
A.3.4.1	Window Type1: 150x240cm		8.00	Unit	€ 308.83	€ 2,470.68	1.39 hrs	1.4 days
A.3.4.2	Window Type2: 275x240cm		0.00	Unit	€ 508.56	€ 0.00	2.54 hrs	0.0 days
A.3.4.3	Window Type3: 140x140cm		2.00	Unit	€ 238.66	€ 477.32	0.75 hrs	0.2 days
A.3.4.4	Window Type4: 90x90cm		2.00	Unit	€ 147.62	€ 295.24	0.31 hrs	0.1 days
A.3.4.5	Exterior door Type1: 90x210		1.00	Unit	€ 523.39	€ 523.39	1.20 hrs	0.2 days
A.3.4.6	Interior sliding door Type2: 80x210		1.00	Unit	€ 338.28	€ 338.28	1.40 hrs	0.2 days
A.3.4.7	Interior swinging door Type1: 90x210		4.00	Unit	€ 343.96	€ 1,375.82	1.20 hrs	0.6 days
A.3.4.8	Interior swinging door Type2: 80x210		12.00	Unit	€ 343.96	€ 4,127.47	1.20 hrs	1.8 days
						€ 9,608.21		4.4 days
A.3.5	Final Touches							
A.3.5.1	Plaster for Interiors		378.73	m2	€ 21.20	€ 8,028.73	0.37 hrs	17.5 days
A.3.5.2	Interior Painting (water-based)		291.56	m2	€ 7.79	€ 2,271.97	0.10 hrs	3.6 days
A.3.5.3	Interior Paintin	*Bathroom*	87.17	m2	€ 9.40	€ 819.22	0.10 hrs	1.1 days
						€ 11,119.92		22.3 days

Figure 34: calculation of total cost and time for non-structure phase roof and third level

ARC.5	Final Touches - exteriors							
A.4.1	External Painting (acrylic-vinyl)		819.86	m2	€ 8.25	€ 6,760.44	0.10 hrs	10.2 days
A.4.2	Plaster for Exteriors		819.86	m2	€ 27.31	€ 22,394.58	0.37 hrs	37.9 days
A.4.3	Banister	*Railings*	62.01	m	€ 145.85	€ 9,044.33	0.53 hrs	4.1 days
						€ 38,199.34		52.3 days
A.4.4	Elevator		1.00		€ 2,748.67	€ 2,748.67		4.0 days
A.4.5	Curtian wall		34.83	m2	€ 202.52	€ 7,053.77	0.53 hrs	2.3 days
A.4.6	Mechanical system							
	Boiler +instalation		4.00	-	€ 1,304.81	€ 5,219.24	8.00 hrs	4.0 days
	Split+instalation		4.00	-	€ 3,294.00	€ 13,176.00	8.00 hrs	4.0 days
						€ 18,395.24		8.0 days

Figure 35: calculation of total cost and time for non-structure phase roof and third level

Considering the future comparison of energy efficiency and providing a building with energy consumption in the class of “A “as preliminary assumption of the hypothesis, it was in demand to find out, the current level of energy consumption in the building.

Consequently, building model was exported to Energy simulation software software produced by BIM in order to evaluate the yearly consumption of building in 1 year. The process of development of using Energy simulation software and steps are explaining in next chapter.

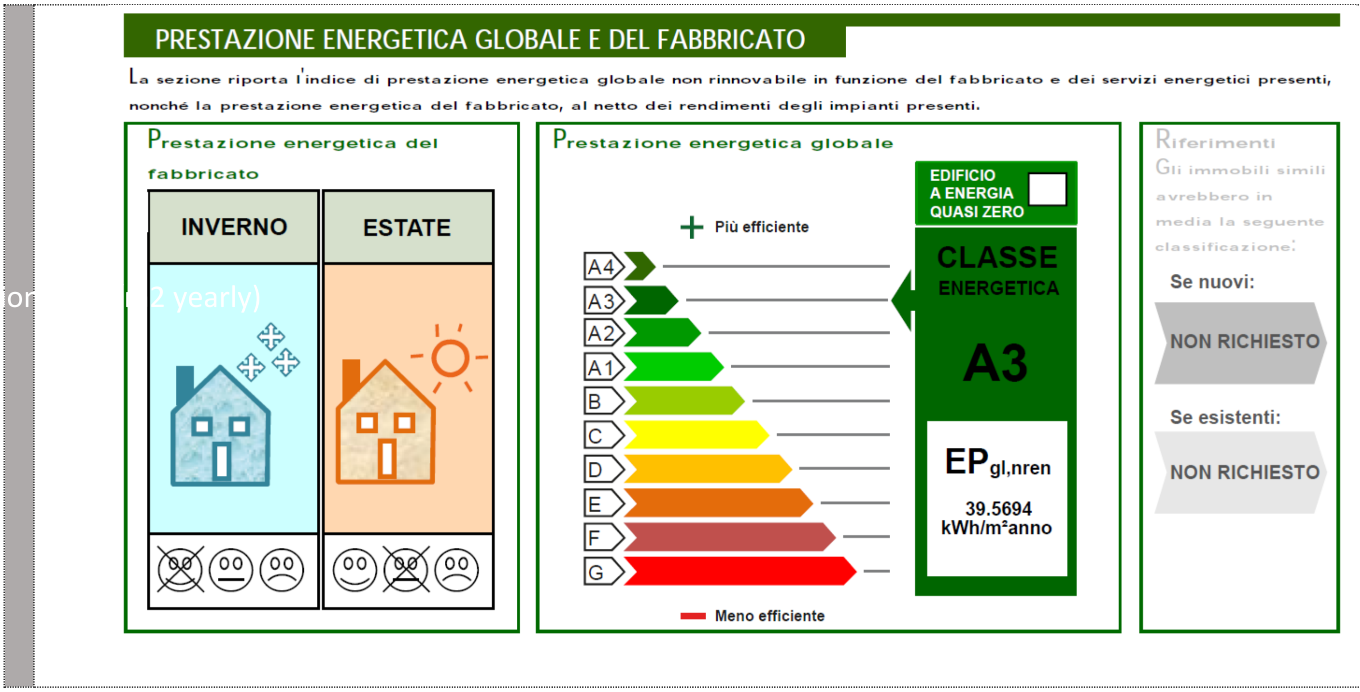


Figure 36: Energy certification for new structure building

2.2 Case study 2 : Refurbishment of old building

2.2.1 General information

In the second case study which is renovation of stories building, the assumption is based on the fact that the age of the building is not replete. By considering that expense of new construction and comparing with improvement of previous case and its structure situation, lead the decision for refurbishment of the building. This goal is aligned for creation of a better class of energy.

For this purpose, we start from analysis of energy consumption in the current situation with Energy simulation software, (software tool produced by BIM) , considering stratigraphy with will represent in the following. As the next stage all of stratigraphy will improve by means of energy class to reach level of A in energy. The final progress of the scheduling will be assumption of cost and timing that is essentially dependence to new intervention that is considered.

2.2.2 Progress of the project

As a preliminary step for energy consumption calculation, the model with IFC format is imported to software and general information related to location and climate is specified.

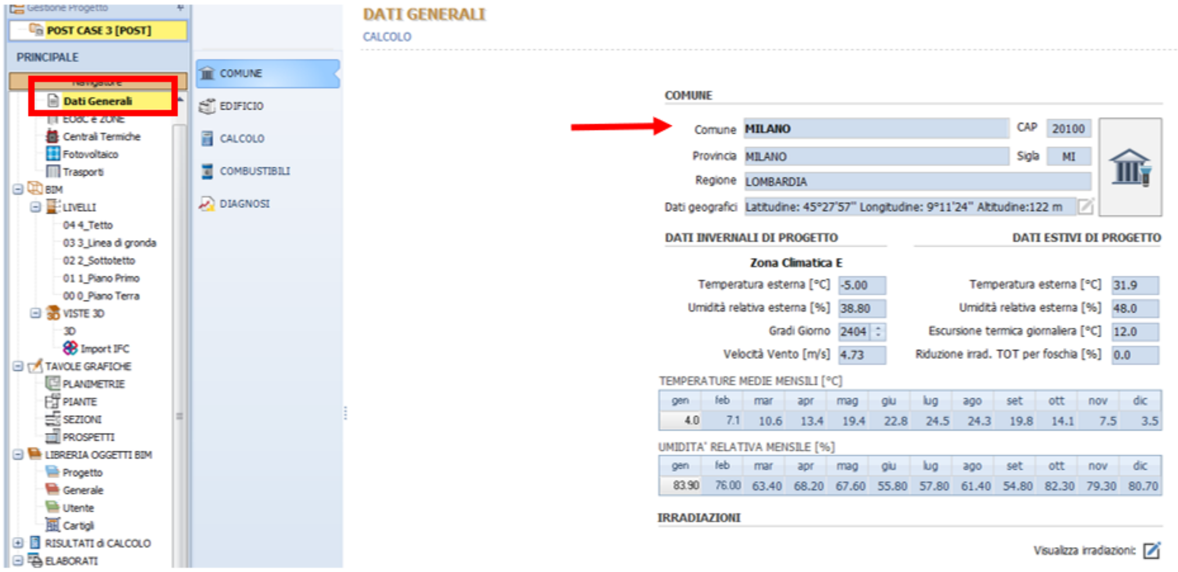


Figure 37: general data in put in energy software simulation

As the second step in EodC, the demand parameters for each hot zone was defined which is consist of heating and cooling system, hot water and ventilation.

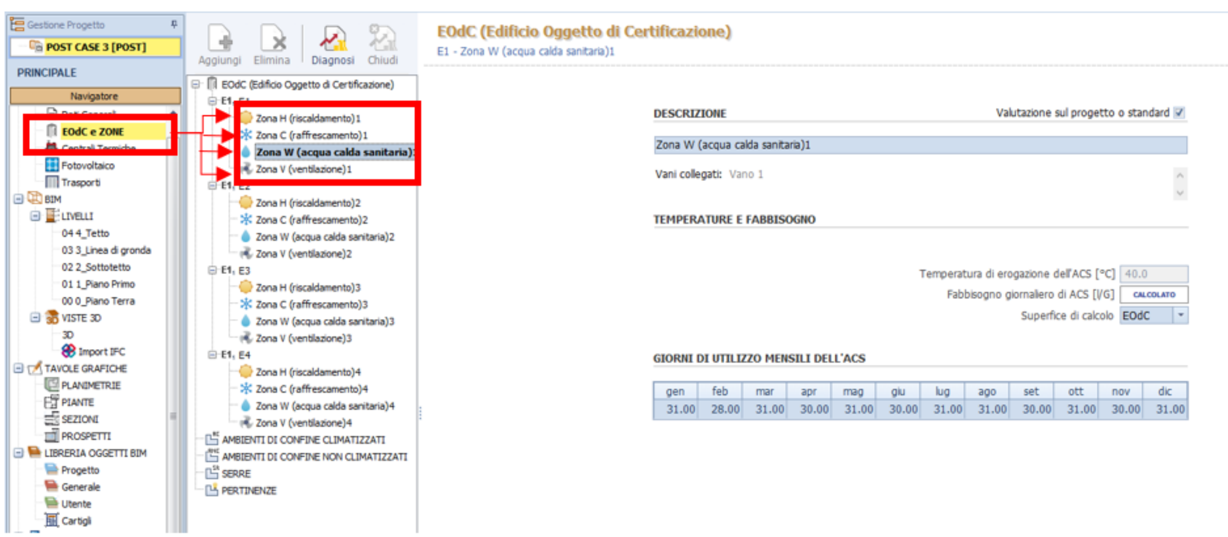


Figure 38: defining zones in energy software simulation

In part of the centrale termichi we can define the kind of generator and split . all the specification of chosen MECH system .

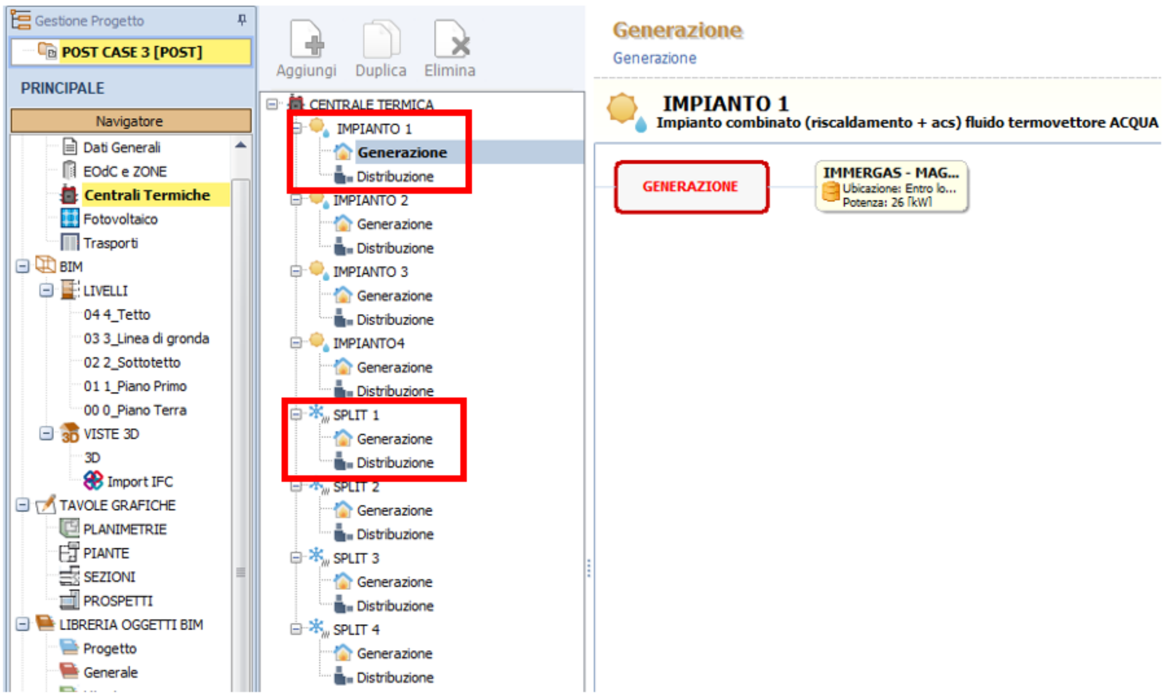


Figure 39: defining hot water, cooling system and heating system in energy simulation software

As the forth step, the statigraphies insert for external walls, roof and windows. After this step we will able to extract the energy grade from software.

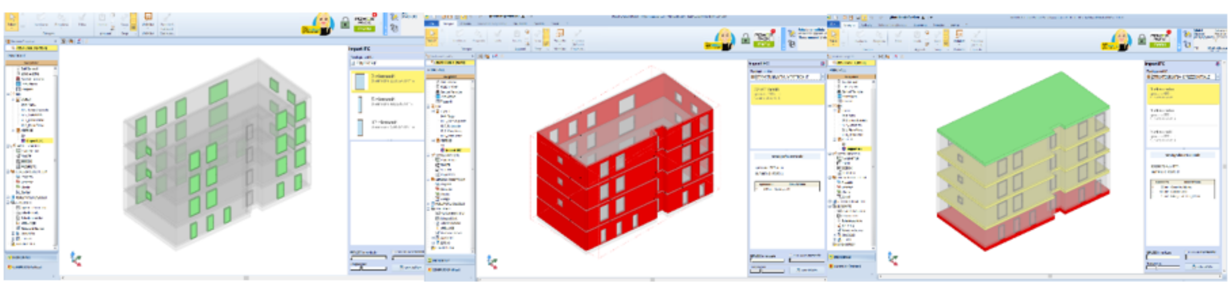


Figure 40: Defining stratigraphy in energy software simulation

Since the target is to improve the class of energy we will do the all the process for 2 cases one in current situation and another in case of having interventions for 3 different stratigraphy of the wall, roof and ground.

In following table we can see the main intervention for roof which is adding 15 insulation which relativity need to remove surface finishing and adding membrane and vapor barrier.

	Main intervention on Roof
1	Remove gravel
2	Insulation 15 cm
3	Water vapor barrier + water resistance membrane

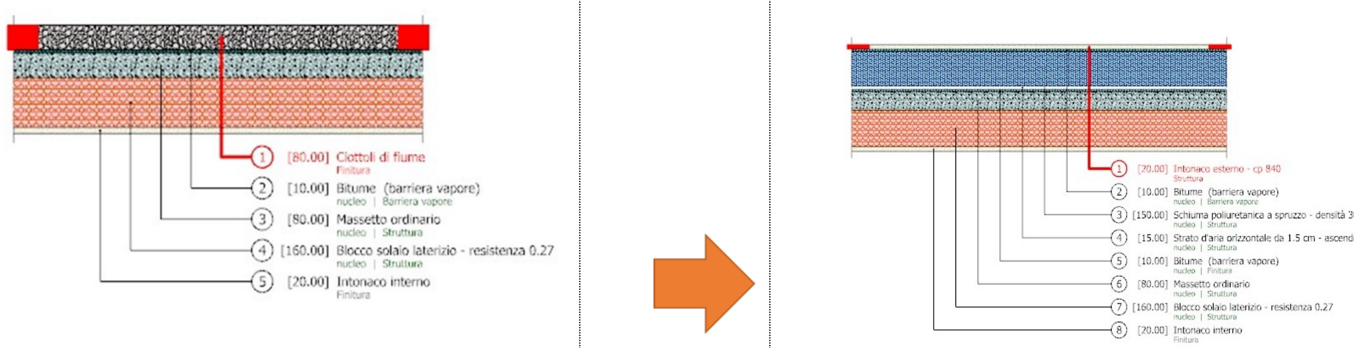


Figure 41: intervention on the roof

The main intervention for ground floor is adding insulation and the same as roof, before we need to remove the plaster and replace it with wood laminate and add vapor barrier and membrane .

	Main intervention on Ground floor
1	Plaster removal

2	water vapor and water-resistance membrane
3	Insulation 20 cm
4	wood laminate

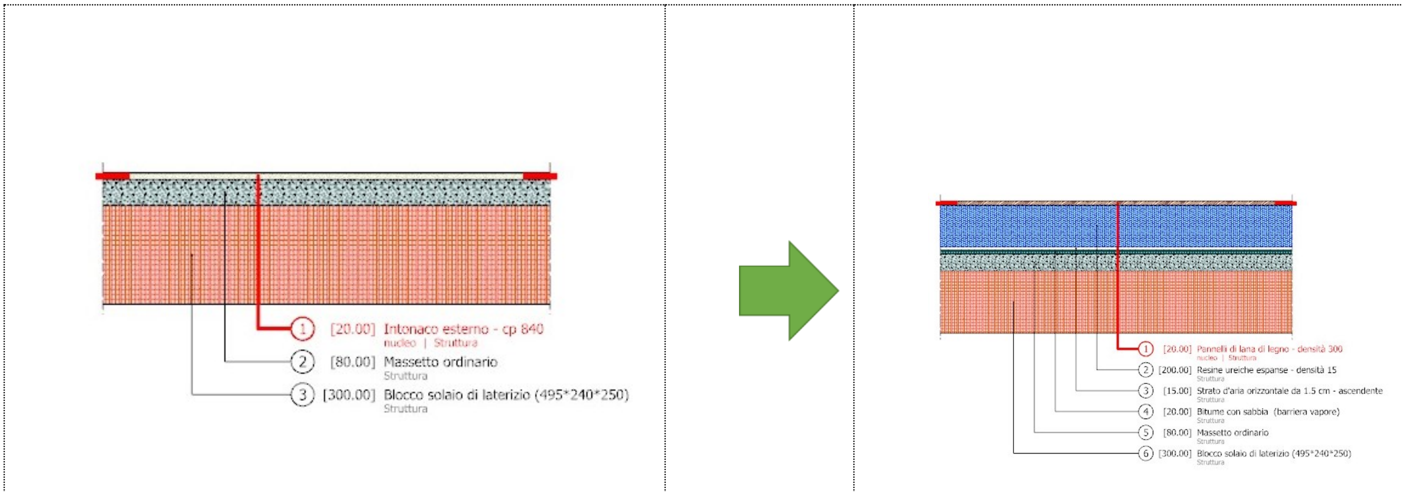


Figure 42: intervention on the ground

The changing in external wall will be adding 15 cm of the insulation in improved case that for preparation of the surface the previous plaster should be remove and then adding on top of the insulation, plaster and painting.

	Main intervention on External wall
1	Remove of plaster
2	Insulation 15 cm
3	Plaster + painting

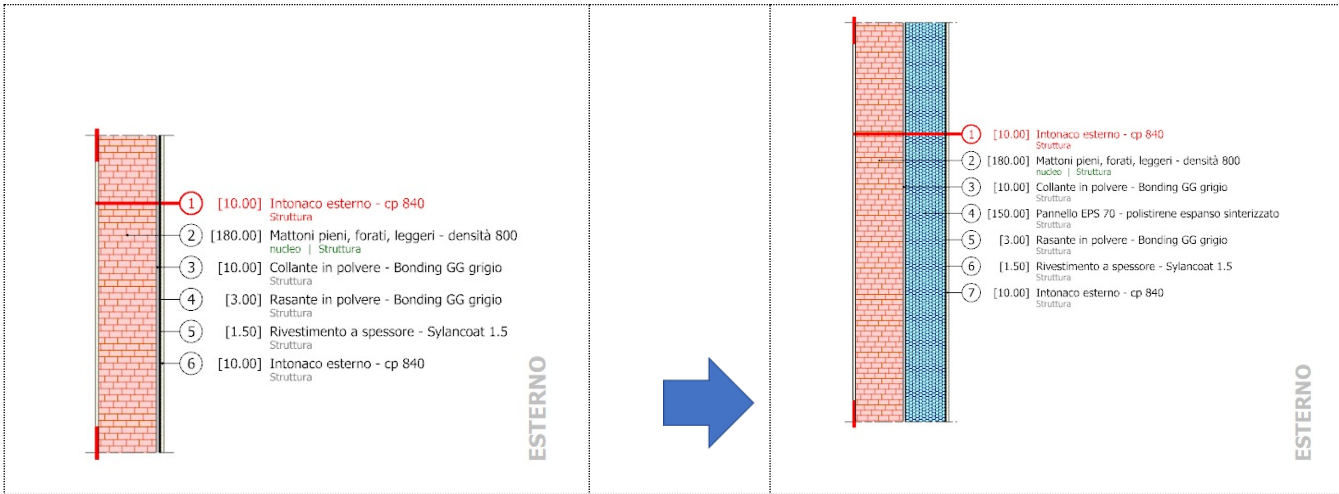


Figure 43: intervention on the wall

Considering the fact that splits using in pervious situation were capable for also new situation they will remain. For heating system the condenser boiler with lower sizing because of higher efficiency was replaced.

	Main intervention on Heating system
1	Replace boiler with smaller and higher efficiency

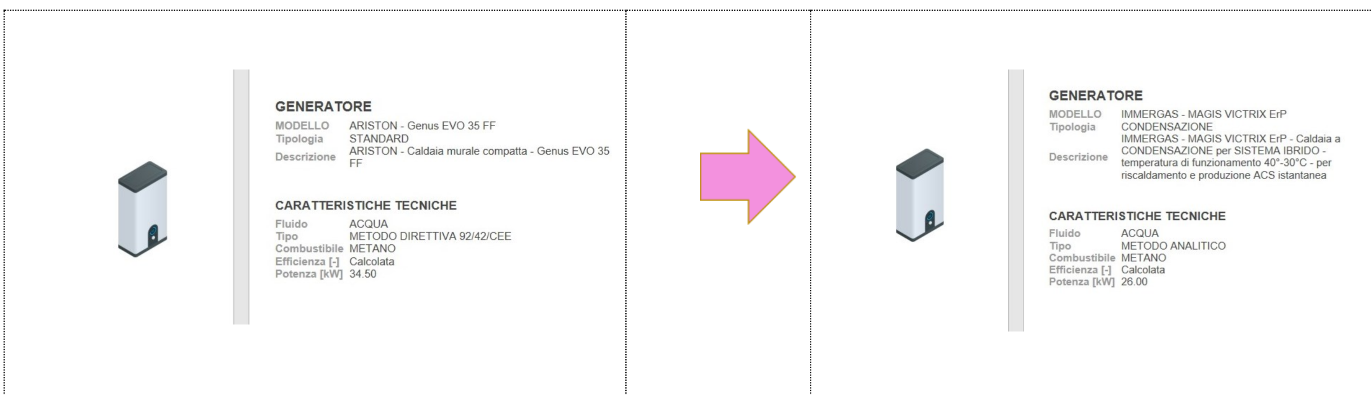


Figure 44: Intervention on heating HVAC system

After all as we can see also in output of software the grade of energy would be possible to reach to grade of A from D . Which refer to this fact that building from 157 KW/m2 start to consume 42 kw/ m2 and it was possible all by the considered interventions above.

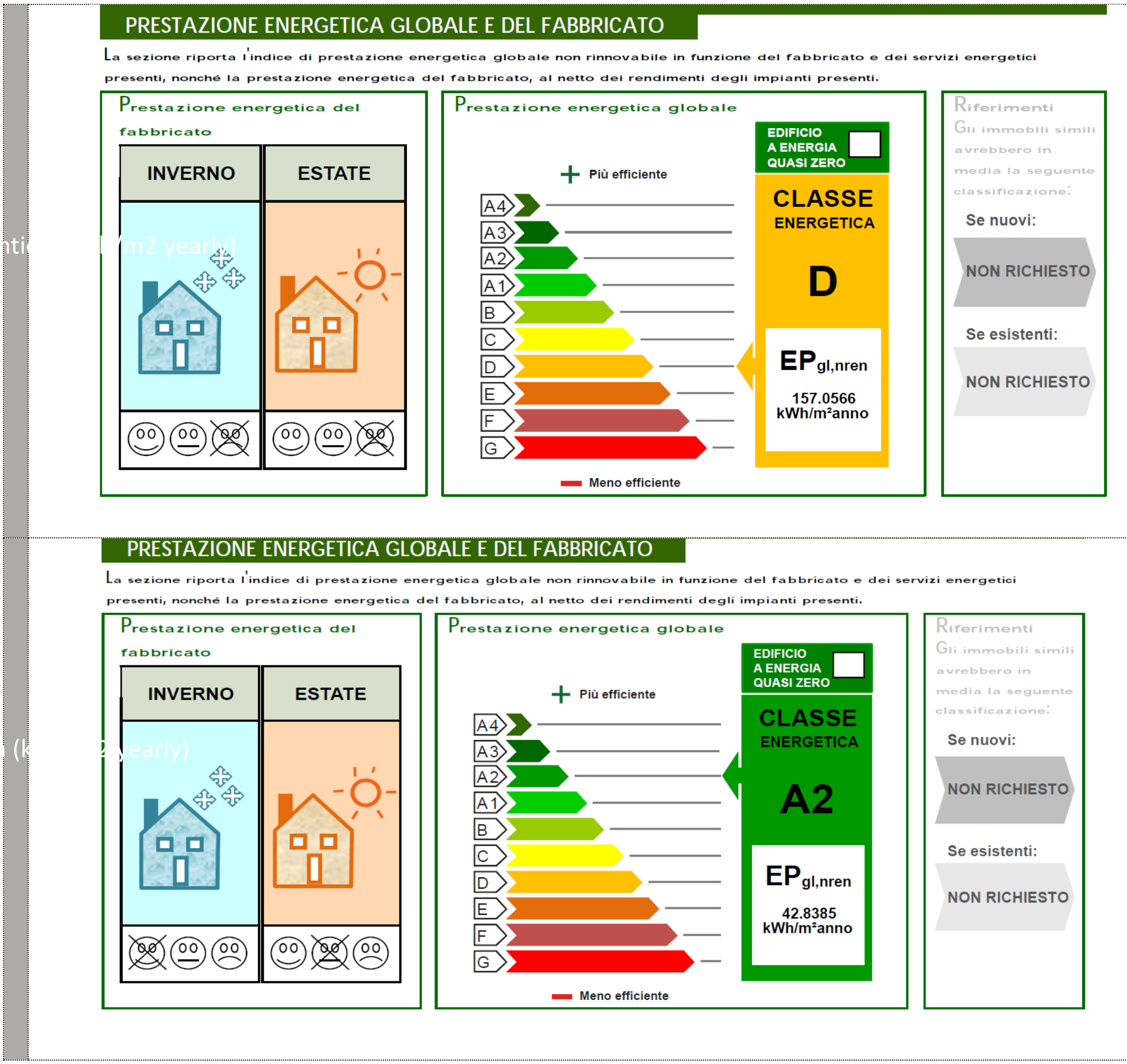


Figure 45: Before and after intervention energy certificate of the building

After relised the interventions that are in demand in the building, we will start with defining right WBS to provide the ability of making approximation about cost and time that will be nedd for this goal.

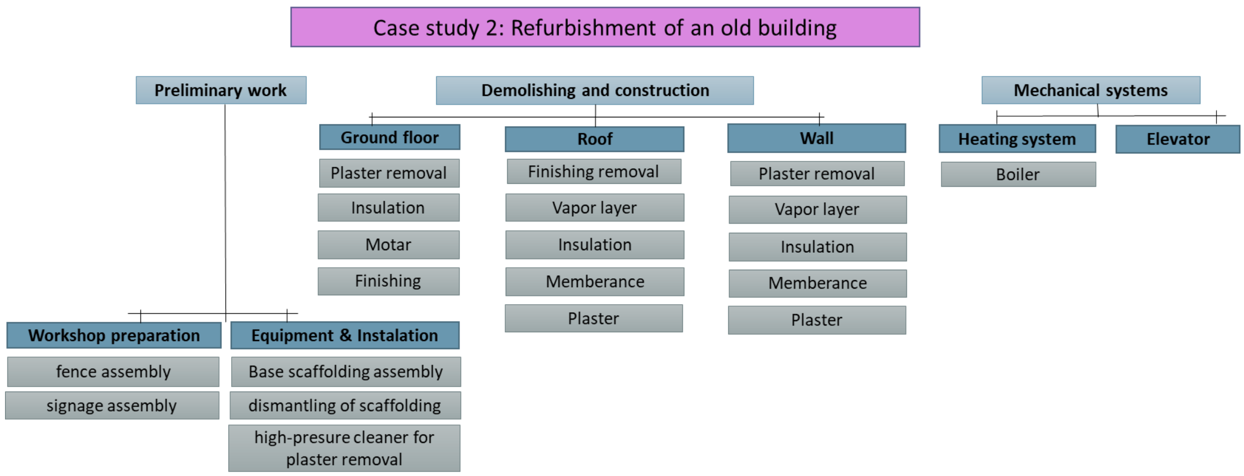


Figure 46: WBS in the case of refurbishment

As case study one we insert model in Quantity take off softwares and assign each layer based on WBS and write correct formula to reach the demand quantity of each of them as case study one.

As we can see all the tasks from preparation, construction and MECH are represented bellow and considering the unit of cost and time we will reach to an estimation about cost and time.

Id	Description	Quantity	Unit	Unitary Cost (Euros/unit)	Total Cost (Euros)	Unitary Duration (hrs/unit)	Total Duration (days)
PRP	Preliminary work						
P.1	Workshop preparation						
P.1.1	fence assembly	82.6	m	7.60 €	627.76 €	0.03 hrs	2.5 days
P.1.2	signage assembly	4		20.13 €	80.52 €	0.03 hrs	0.02 days
					708.28 €		2.5 days
P.2	Equipment & Instalation						
P.2.1	scaffolding assembly	819.86	m2	14.92 €	12,232.38 €	0.04 hrs	4.1 days
P.2.2	dismantling of scaffolding	819.86	m2	14.92 €	12,232.38 €	0.04 hrs	4.1 days
P.2.3	high-presure cleaner for plaster removal	1	-			2.00 hrs	0.3 days
					24,464.77 €		8.4 days

Figure 47: calculation of total cost and time for preliminary work

Id	Description	Quantity	Unit	Unitary Cost (Euros/unit)	Total Cost (Euros)	Unitary Duration (hrs/unit)	Total Duration (days)
CON	Demolishing and construction						
C.1	Ground floor						
C.1.1	plaster removal	200.94	m2	€ 12.41	2,493.73 €	0.04 hrs	1.0 days
C.1.2	Insulation Layer *Ground Floor*	200.94	m2	€ 22.85	4,591.52 €	0.08 hrs	1.9 days
C.1.3	Screed: Mortar bedding layer + Heating membrane	200.94	m2	€ 37.42	7,520.26 €	0.37 hrs	9.3 days
C.1.4	Flooring type 3 *Wooden Laminate Finishing*	200.94	m2	€ 27.29	5,483.96 €	0.18 hrs	4.5 days
					20,089.46 €		16.7 days
C.2	Roof						
C.2.1	finishing removal	341.07	m2	€ 12.41	4,232.68 €	0.04 hrs	1.7 days
C.2.2	Vapor layer	341.07	m2	€ 13.57	4,629.94 €	0.10 hrs	4.3 days
C.2.3	Insulation Layer	341.07	m2	€ 40.91	13,952.05 €	0.08 hrs	3.2 days
C.2.4	Water-resistant membrane	341.07	m2	€ 27.00	9,209.06 €	0.10 hrs	4.3 days
C.2.5	Plaster	341.07	m2	€ 42.36	14,447.18 €	0.50 hrs	7.0 days
					46,470.91 €		20.4 days
C.3	External wall (façade)						
C.3.1	plaster removal	819.86	m2	€ 12.41	10,174.52 €	0.04 hrs	4.1 days
C.3.2	Vapor layer	819.86	m2	€ 13.57	11,129.46 €	0.10 hrs	10.2 days
C.3.3	15 cm Exterior Coat Insulation	819.86	m2	€ 29.19	23,928.60 €	0.12 hrs	12.3 days
C.3.4	Water-resistant membrane	819.86	m2	€ 27.00	22,136.76 €	0.10 hrs	10.2 days
C.3.5	Exteriors plaster	819.86	m2	€ 27.31	22,394.58 €	0.37 hrs	37.9 days
C.3.6	External Painting (acrylic-vinyl)	819.86	m2	€ 8.25	6,760.44 €	0.10 hrs	10.2 days
					96,524.36 €		85.1 days

Figure 48: calculation of total cost and time for demolishing and construction of renovated building

Id	Description	Quantity	Unit	Unitary Cost (Euros/unit)	Total Cost (Euros)	Unitary Duration (hrs/unit)	Total Duration (days)
MECH	Mechanical systems						
M.1	Heating system						
M.1.1	boiler (new)+instalation	4		€ 1,304.81	5,219.24 €	8.00 hrs	4.0 days
M.2	Lift						
M.2.1	Elevator	1	-	€ 2,748.67	2,748.67 €	32.00 hrs	4.0 days

Figure 49: calculation of total cost and time for mechanical system

3 Result and Conclusion

3.1 Result

Regarding assistance of building information modeling in AEC in general, and specifically in this project in construction management, we were able to extract the amounts related to time and cost in demand for eventually, case study 1 where it was decided to reconstruct in order to meet the energy efficiency demand imposed by law, as well as case study 2 where it was decided to be renovated.

The goal of this comparison is to arrive at the point of view that can be used to make a statement regarding the type of strategy that can be used to obtain the building's demand energy certificate that can be reconstruct or renovation. It is important to note that both case studies met the energy certification issued by Energy simulation software, BIM software, which is aligned with the Italian government.

Meanwhile, the work breakdown structure, which included all of the necessary operations for building renovation and reconstruction, was modeled as a tree diagram, and bills of quantities were generated in Quantity take off software by using the WBS allocated to each layer.

Progress of project was followed by estimating the time and cost of material, human resources, and equipment, as well as indirect costs, for each task. The use of a Gantt chart could aid in the scheduling of activities. As can be seen in the bar charts below, all of the activities based on WBS are shown for the first case study (reconstruction) on the left, with the length of each bar that representing the start and ending date for each activity for two hypotheses of provisional and executional situations.

3.1.1 Case study 1: Reconstruction

The represented Gantt charts were completed in the us-BIM platform software (BIM) and demonstrate the starting date as 18/01/2022 and ending date of 30/07/2022consisting of 388 days as total duration for the case of reconstruction of 4-stories residential building.

As its also represented in the Figure 50 the first level of tasks in the case reconstruction are divided in to the 3 main sublevel which are preliminary phase, structural phase and non-structural phase where demand in order 129, 144 and 208 days to be construct.

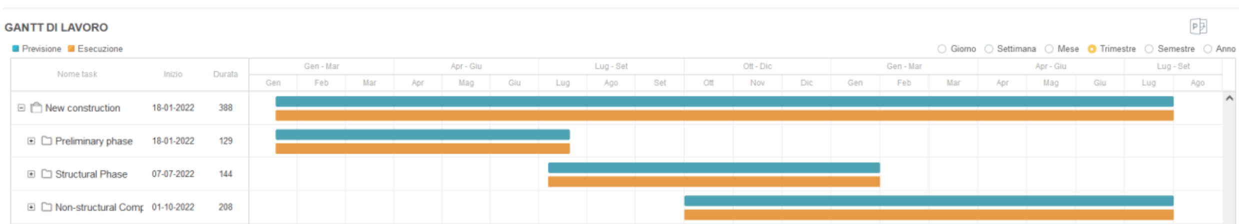


Figure 50: Presentation of first level of WBS on Gantt chart (Reconstruction) , Management software platform

The overlap between the preliminary and structure phases is owing to the fact that, after laying the foundation, structural work can begin without attention to the landscape (Figure 51).

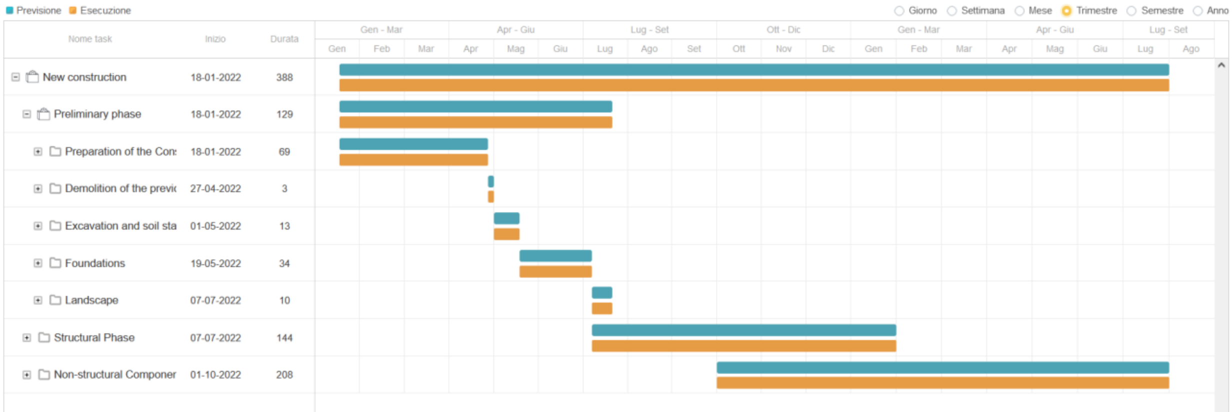


Figure 51: Presentation of expansion in second level of WBS on Gantt chart for preliminary phase (Reconstruction) , Management software platform

The second key overlapping is due to structural and non-structural elements, where non-structural elements such as wall and floor finishing could be placed in the ground level at the same time as structural activities in the second story due to the presence of exterior stairs. (Figure 52).

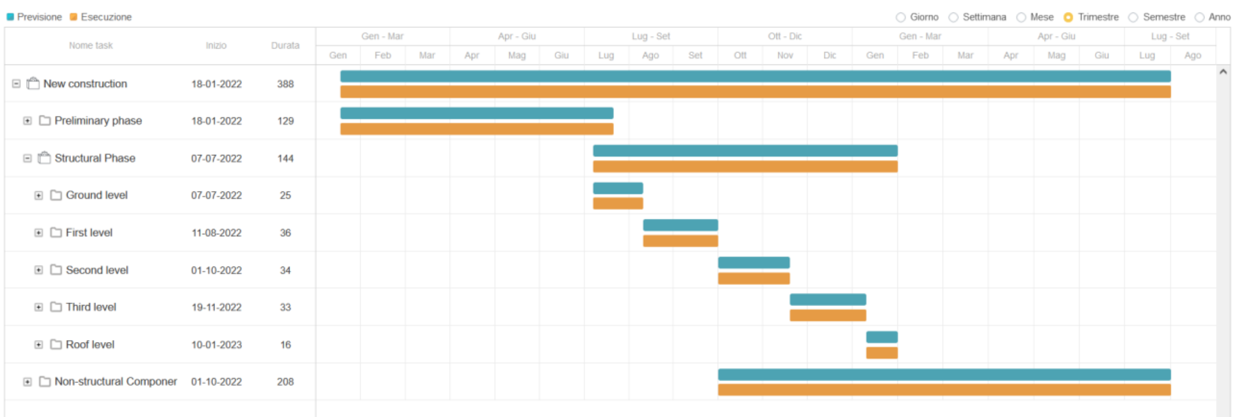


Figure 52: Presentation of expansion in second level of WBS on Gantt chart for structural phase (Reconstruction) , Management software platform

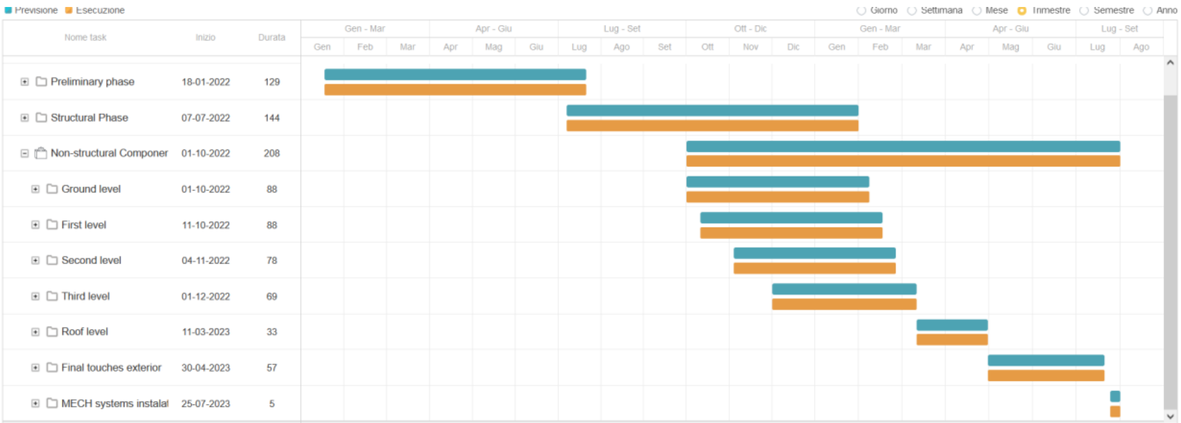


Figure 53: Presentation of expansion in second level of WBS on Gantt chart for non-structural phase (Reconstruction), Management software platform

In the next step, the total cost of construction and also assigned to human resources, material and equipment is represented bellow based on the values which were assigned each single task as it reviewed in the previous chapter.

Importi	Prestazioni	397.949,44 €	Totale: 703.447,18 €
	Risorse	268.399,00 €	
	Spese	37.098,74 €	

Table 8: representation of total cost in human resources, material and equipment (indirected cost included) (Reconstruction), Management software platform

So based on last analysis the total cost for construction of 4 stories building in 388 days is about 703000 euros in Millan. The Figure 54 indicate the distribution of the cost along the time of construction based on 3 main portion of expenses which are human resources, material and equipment. The cumulative value of same three parameters in cost are demonstrated in Figure 55.

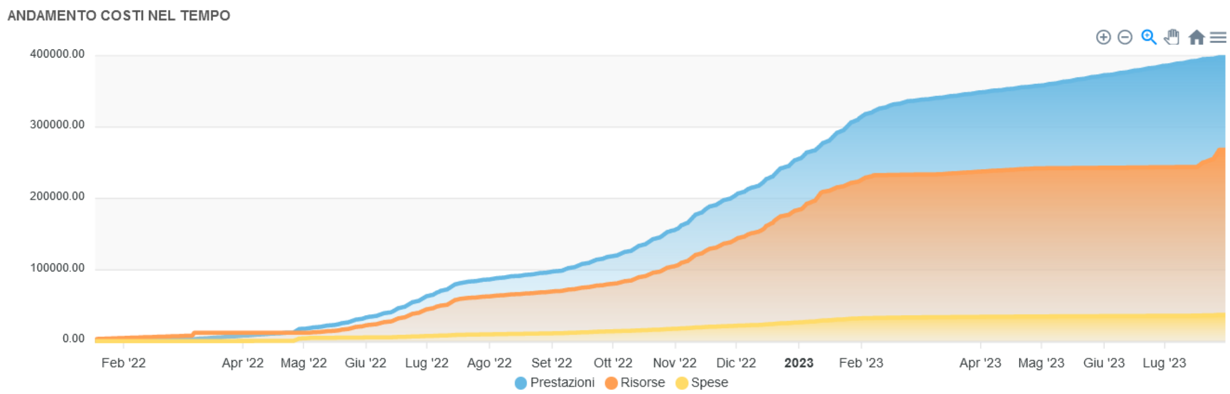


Figure 54: division of total cost in to the human resources, material and equipment during the time(Reconstruction), Management software platform

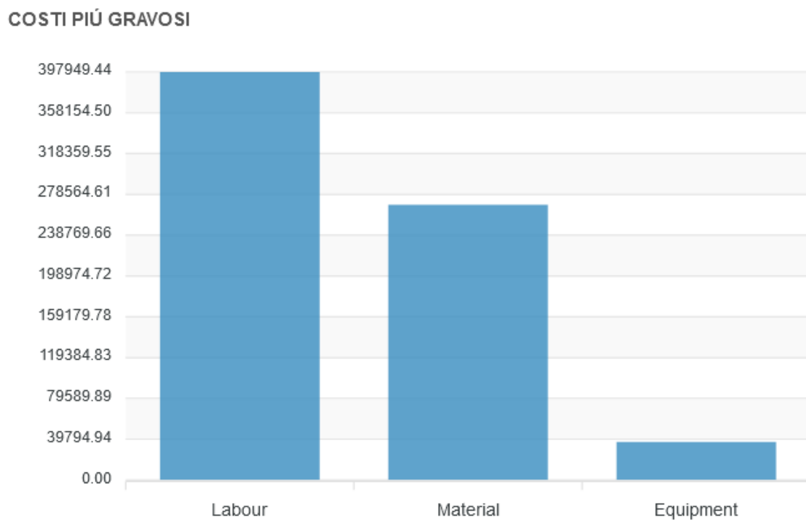


Figure 55: Cumulative cost value of the human resources, material and equipment (Reconstruction), Management software platform

3.1.2 Case study 2: Renovation

The scheduling of the time in the case of renovation are represented in the figures in the following by Gantt chart. Its assumed the starting date is on 27/04/2022 so the operation will be ended on 25 /05/2022 which consist of 102 days.

Figure 56 represent the division of the WBS in the first level which in the case of renovation is divided in to three branch of preliminary work, demolishing and construction, and mechanical system.

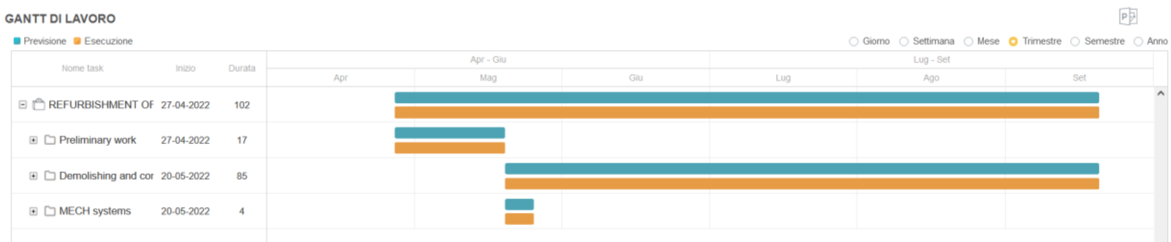


Figure 56: Presentation of first level of WBS on Gantt chart (Renovation) , Management software platform

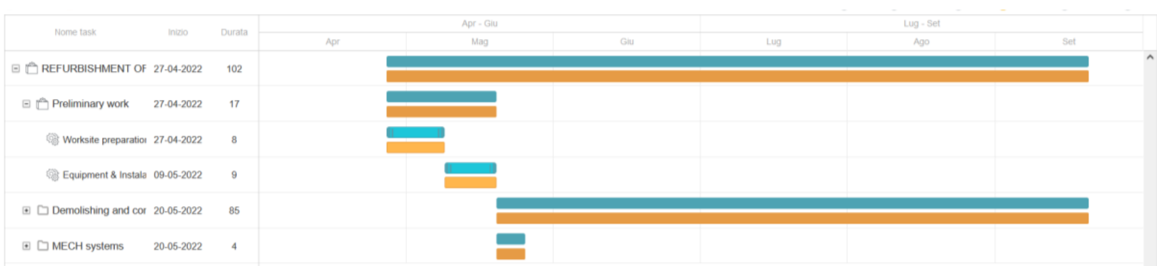


Figure 57: Presentation of expansion in second level of WBS on Gantt chart for preliminary phase (Renovation) , Management software platform

As it can be seen , two other activity demolishing and construction and installation of the mechanical system will started after preliminary activity and preparation of the site since they don’t have any intersection (Figure 58). So they will have overlapping in the Gantt chart regardless of any problem.

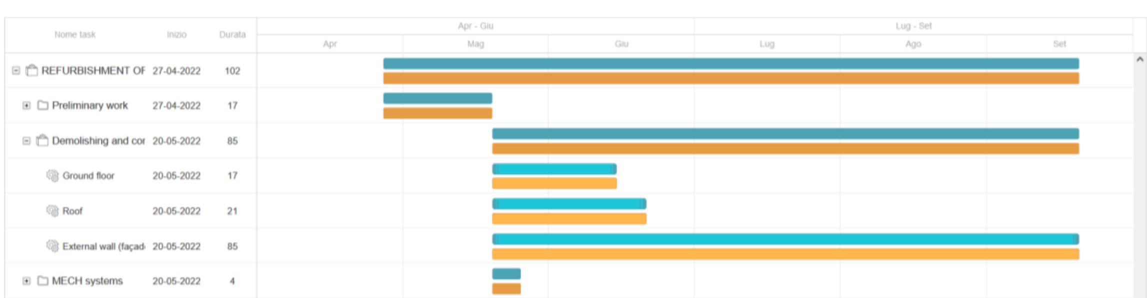


Figure 59: Presentation of expansion in second level of WBS on Gantt chart for demolishing and construction phase (Renovation) , Management software platform

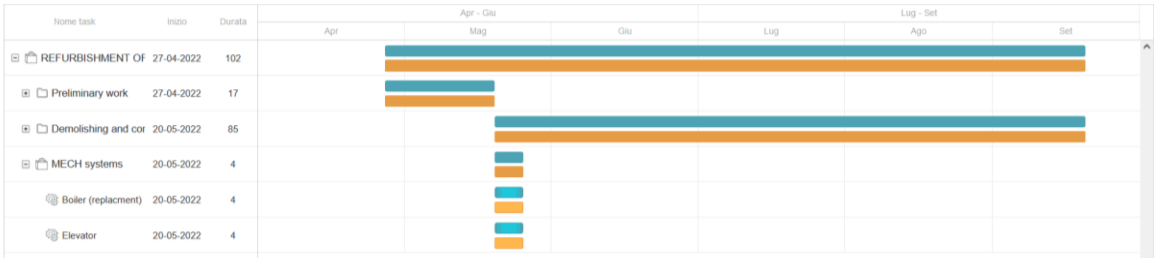


Figure 60: Presentation of expansion in second level of WBS on Gantt chart for Mechanical phase (Renovation) , Management software platform

In the Table 9 The total cost amount is calculated using three major subcategories: human resources, materials, and equipment. The biggest amount, as expected, is related to labor (about 118275 euro) and material (approximately 710000 euro), with the lowest portion being tied to equipment costs (around 710000 euro). Table 11: representation of total cost in human resources, material and equipment (indirected cost included) (Renovation), us-BIM platform represent also the total cost extracted by us-BIM platform by around 200000 euro.

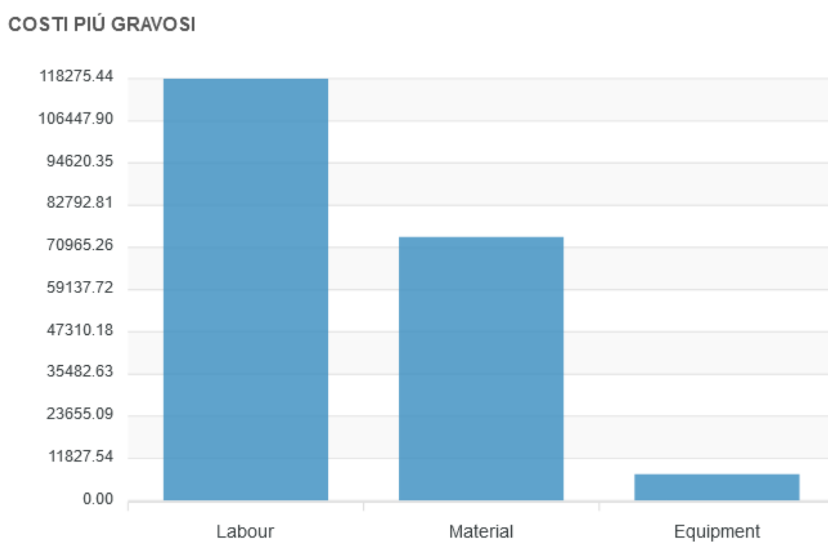


Table 10: Cumulative cost value of the human resources, material and equipment (Renovation), us-BIM platform

Importi			
	Prestazioni	118.275,44 €	Totale: 199.579,92 €
	Risorse	73.866,00 €	
	Spese	7.438,48 €	

Table 11: representation of total cost in human resources, material and equipment (indirected cost included) (Renovation), us-BIM platform

Figure 61 is representing the expenses of 3 main subcategory of the total cost for renovation during time started from May to September 2022 .

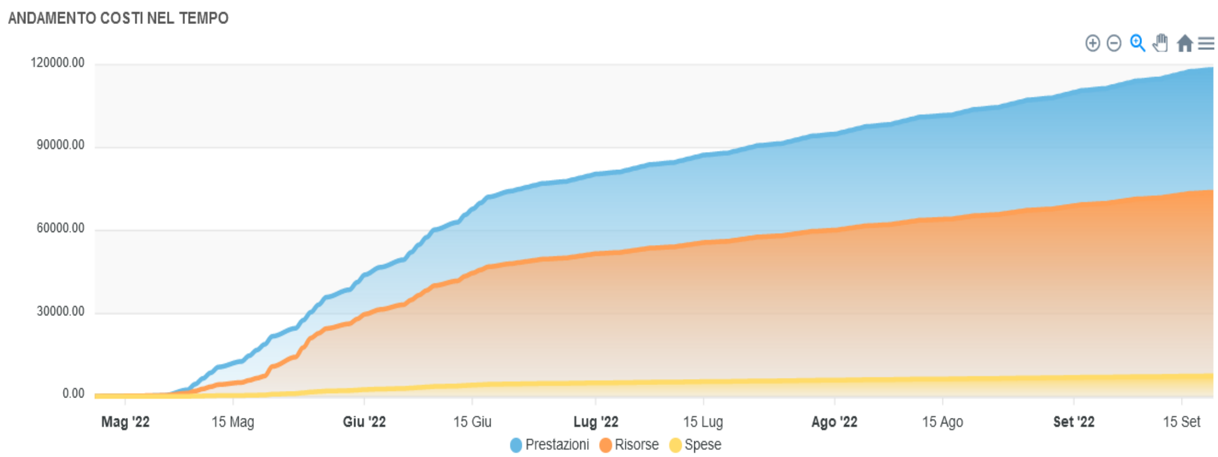


Figure 61: division of total cost in to the human resources, material and equipment during the time(renovation) , us-BIM platform

3.2 Conclusion

Finally, based on the age of the structure and the life span for which it was created, we arrive to a position where we can make an informed judgment regarding the benefits that can be obtained through renovation or, conversely, reconstruction. However, it should be mentioned at the outset that the life cycle of a building might vary according to a variety of factors such as location, function, environment, and so on. Experts can estimate it as well, utilizing technologies to diagnose structural, material, or even building height, and etc.

In this part the standard lifespan for residential building is considered as 50 years. The question that must be responded is defining the critical year , based on hypothesis life span of building and total cost and time for case of reconstruction and renovation, that renovation benefits place in the lower level in compare with construction.

Figure 63 represent the cost-average over lifespan of the building as a most important parameters of Cost–benefit analysis. In this curve, the vertical axis shows the distributed cost based on the number of using years, While the horizontal axis shows the building age. This building is assumed that has design lifespan of 50 years based on EN 1990. (Union, 2002)

Design working life category	Indicative design working life (years)	Examples
1	10	Temporary structures [(1)]
2	10 to 25	Replaceable structural parts, e.g. gantry girders, bearings
3	15 to 30	Agricultural and similar structures
4	50	Building structures and other common structures
5	100	Monumental building structures, bridges, and other civil engineering structures
(1) Structures or parts of structures that can be dismantled with a view to being re-used should not be considered as temporary.		

Figure 62: Design Service Life—DSL category , EN 1990

It is predictable that the renovation of this building will not be economical during the last years of its lifespan. Therefore, defining the exact year that decision is making for improvement of energy efficiency, plays an important role in cost benefits of the reconstruction. On the other hand, in the new construction of the building (according to the 50-year life of the new building), the total cost is divided by the building lifetime (50 years) regardless of the current building age. As a results, we use the following equation for the new construction:

Y=(Total Cost)/(Lifespan)=703000€ /50 years=14.06

And the following equation for the renovation:

Y=(Total Cost)/(Lifespan)=200000 € /(51-X) years

In the above equation, X is building age in terms of years. The intersection of the two curves represents the threshold year which the new construction will be cost-effective after this year. The threshold is 36.77 year-old where the distributed cost is 14 euro.

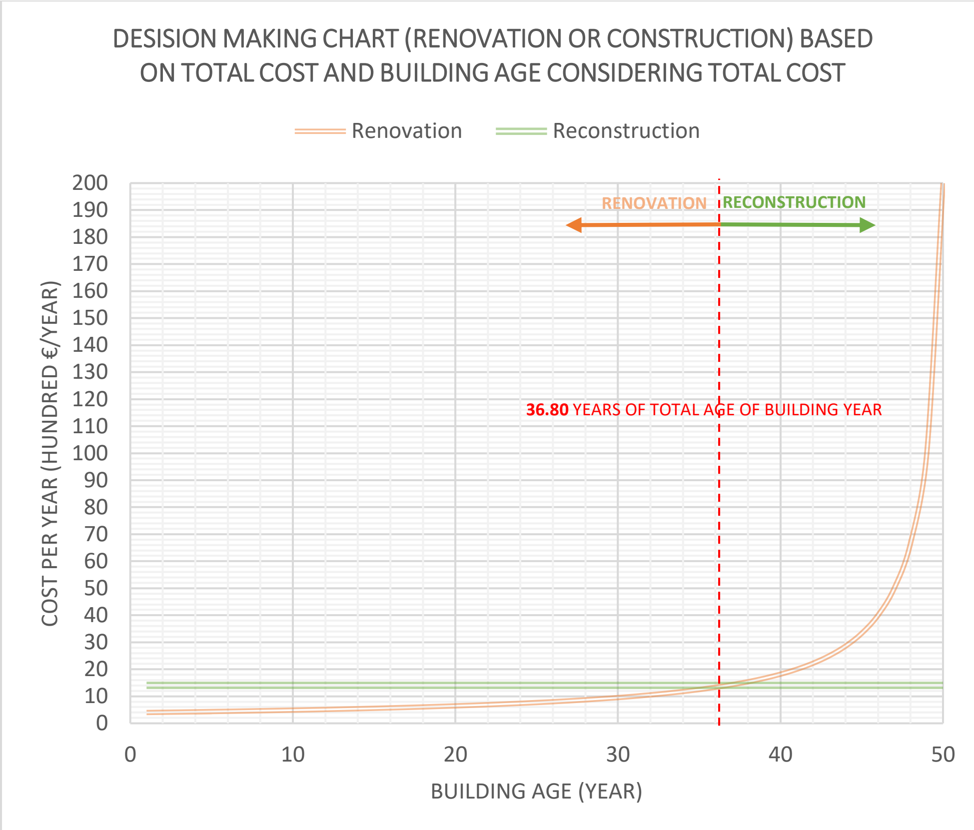


Figure 63: decision making chart based on total cost

Same logic can be also true for reaching to critical age of building that renovation will eliminate its own benefits compare with reconstruction but in case of time of operation for both cases. Since Renovation is depend on the structure and consequently time after 37 years passing from birth of the building, it can't be a smart choice not only in the sense of cost benefits but also the time demand for operation. As a consequence, for the new construction, we apply the following equation:

Y=(Total Time)/(Lifespan)=388 days /50 years=7.76

And the following equation for the renovation:

Y=(Total Time)/(Lifespan)=102 days /(51-X) years

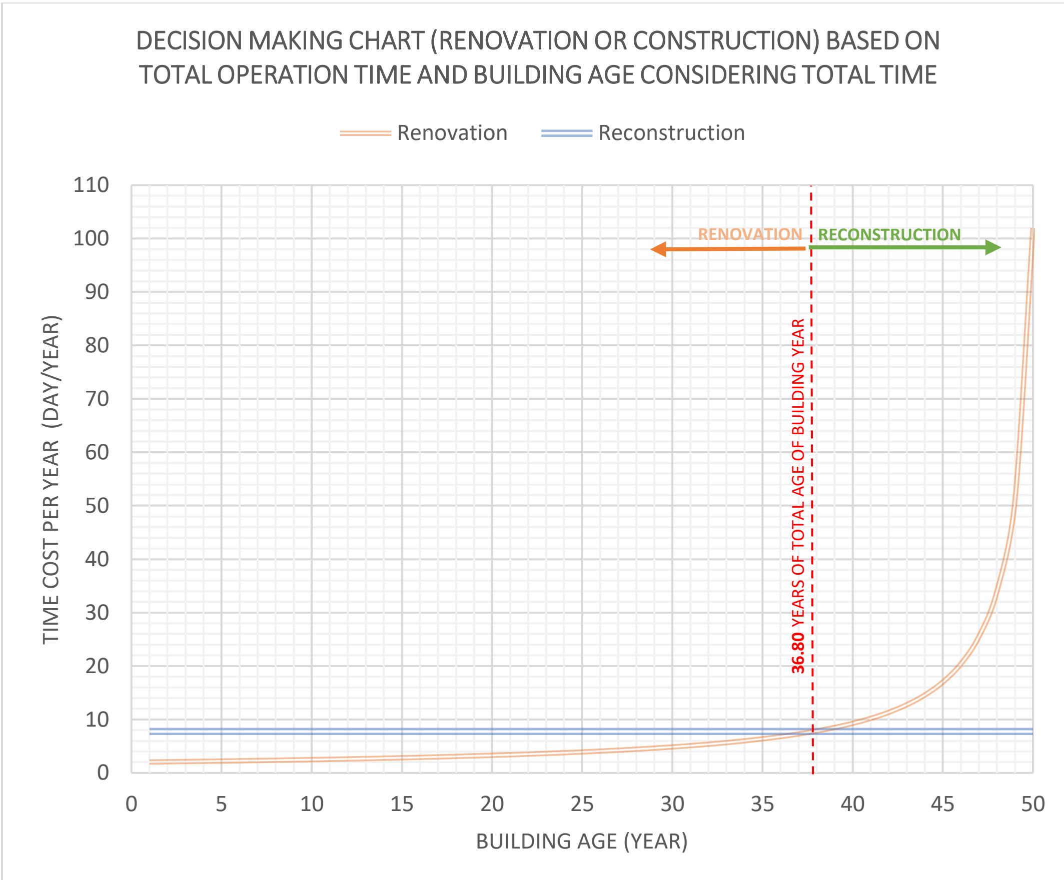


Figure 64: decision making chart based on total time

Finally, the graphs could illustrate that if a building is 20 years old, renovation will benefit in the sense of cost and time , the client more, and or if it is 40 years old, then reconstruction will benefit the client more.

It's also worth mentioning that this project is offering a simple multidisciplinary method based on some hypothesis that may be customized for each project, as well as a goal of avoiding complicity by not including too many parameters.

4 Annex

5 Biography

Anderson Earl B. Hales, S. R. (1986). Critical path method applied to research project planning: Fire Economics Evaluation System (FEES). *Gen. Tech. Rep.*, 12 p.

Bryde, D., Broquetas, M., & Volm, J. M. (2013). The project benefits of building information modelling (BIM). *International Journal of Project Management*, *31*(7), 971–980. https://doi.org/10.1016/j.ijproman.2012.12.001

Green Building Council Italia. (2019). *Energy efficiency of buildings in Kosovo*. 47–58. https://doi.org/10.5592/co/phdsym.2019.04

Islam, M. J. (2021). Program Evaluation and Review Technique (Pert) and Critical Path Method (Cpm): a Case Study. *Program Evaluation and Review Technique (Pert) and Critical Path Method (Cpm): A Case Study*, *April*, 1583–1587.

John Wiley & Sons, I. (2011). BIM Handbook. In *John Wiley & Sons, Inc* (2nd ed.). John Wiley & Sons, Inc.

Kephalopoulos, S., Geiss, O., Barrero-Moreno, J., D'Agostino, D., & Paci, D. (2017). Promoting Healthy and Highly Energy Performing Buildings in the European Union: National Implementation of Related Requirements of the Energy Performance Buildings Directive (2010/31/EU). In *Science for Policy report*. https://doi.org/10.2760/73595

Mubarak, S. (2010). Bar(Gantt)Charts. *Construction Project Scheduling and Control*, *May 2010*, 13–19. https://doi.org/10.1002/9780470912171.ch2

Neff, G., Fiore-Silfvast, B., & Dossick, C. S. (2010). A case study of the failure of digital communication to cross knowledge boundaries in virtual construction. *Information Communication and Society*, *13*(4), 556–573. https://doi.org/10.1080/13691181003645970

Pritchard, C. L. (2019). Work Breakdown Structure. *The Project Management Drill Book*, *June*, 147–156. https://doi.org/10.4324/9780203741764-14

Rogério dos Santos Alves; Alex Soares de Souza, et all. (2014). BIM and Construction Management - Proven tools, methods, and workflows. In *Igarss 2014* (Issue 1, pp. 1–5).

Rokooei, S. (2015). Building Information Modeling in Project Management: Necessities, Challenges and Outcomes. *Procedia - Social and Behavioral Sciences*, *210*, 87–95. https://doi.org/10.1016/j.sbspro.2015.11.332

Salvalai, G., Masera, G., & Sesana, M. M. (2015). Italian local codes for energy efficiency of buildings: Theoretical definition and experimental application to a residential case study. *Renewable and Sustainable Energy Reviews*, *42*(November 2013), 1245–1259. https://doi.org/10.1016/j.rser.2014.10.038

Smith, P. (2014). BIM & the 5D Project Cost Manager. *Procedia - Social and Behavioral Sciences*, *119*, 475–484. https://doi.org/10.1016/j.sbspro.2014.03.053

Union, E. (2002). *H E U R O P E a N N I O N*. *1*(2002).

Wierzbicki, M., & De Silva, C. W. (2011). *BIM-History and Trends*. https://www.researchgate.net/publication/259390230